1997

LAKE AND WETLAND MONITORING

PROGRAM REPORT

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Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 33 Kansas lakes and wetlands during 1997. Nine of these lakes were federal reservoirs, twelve were State Fishing lakes (SFLs), and the remaining 12 represented city or county lakes. In addition to routine lake surveys, 17 public wetland areas were sampled as part of an Environmental Protection Agency (EPA) grant. These wetlands, including those seven wetland areas that are part of the official KDHE monitoring network, will be surveyed for the next three years as part of a baseline study of wetland water quality in Kansas. The results of this sampling will be the basis of a final project report slated for completion during 2001.

Of the 33 lakes surveyed during 1997, twelve indicated reasonably constant trophic states since their last surveys while eleven indicated an increased trophic state. Eight lakes were surveyed in 1997 that indicated an improvement in trophic state since their last water quality survey. The remaining two lakes had not been surveyed previously. Phosphorus was identified as the primary environmental factor limiting algae growth in 61% of lakes surveyed during 1997. The potential of light limitation was indicated in several lakes, but of significance in only two.

A total of 89 exceedences of the Kansas numeric water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, were documented in the surface waters of the 33 surveyed lakes. Twenty-nine (33% of the total) of these exceedences concerned aquatic life support criteria. Thirty-seven concerned water supply, livestock watering, or irrigation criteria. Twenty-three concerned contact and non-contact recreation uses. In all, a total of 45 exceedences occurred in the lakes with established designated uses (50% of the total).

Atrazine was the most often detected pesticide in Kansas lakes during 1997. Nineteen lakes (58%) had detectable concentrations of atrazine within their main bodies. These detections ranged in concentration from 0.33 to 13.00 ug/L. Dual (metolachlor) was detected in 15 lakes (concentration ranging from 0.28 to 4.50 ug/L). Other detected pesticides included alachlor (7 lakes, concentrations of 0.12 to 1.3 ug/L), 2,4-D (one lake, concentration of 2.10 ug/L), cyanazine (one lake, concentration of 1.5 ug/L), and acetochlor (two lakes, concentrations of 0.27 and 0.29 ug/L). In addition, the atrazine metabolite deethylatrazine was detected in 13 lakes, at concentrations of 0.33 to 5.30 ug/L.

Five of the 33 lakes (15%) exceeded the EPA Maximum Contaminant Level (MCL) for atrazine in drinking water (3.0 ug/L), and two of these are current sources for municipal water supply.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, by determining regional and time trends for those impoundments, and by identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sample stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake were reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 115 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The program remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from lake ecological processes and algae blooms.

Overview of the 1997 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 33 Kansas lakes during 1997. Nine of these lakes are large federal lakes last sampled in 1994 or part of the recent Governor's Water Quality Initiative in the Kansas River Basin, twelve are State Fishing Lakes (SFLs), and the remaining twelve are city/county lakes (CLs and Co. lakes, respectively). Thirteen of the 33 surveyed lakes serve as either primary or back-up municipal and/or industrial water supplies.

As part of the Governor's Water Quality Initiative in the Kansas/Lower Republican River Basin, seven lakes were targeted for sampling on an annual basis during 1996-to-1998. These lakes include Tuttle Creek, Milford, Clinton, and Perry Lakes, all feeding into the Kansas River. Also included are three smaller lakes within targeted watersheds in the Black Vermillion River Basin upstream from Tuttle Creek Lake (Centralia Lake) and the Grasshopper Creek Basin upstream of Perry Lake (Mission Lake and Atchison County Lake).

As part of an EPA funded study, 17 public wetland areas will be surveyed each year from 1997 to 2000. These include the seven public wetland areas that are part of the Lake and Wetland Monitoring Program Network. The purpose of this study is to produce a baseline picture of water quality conditions in Kansas wetlands. Results from this four year sampling effort will be summarized in a final project report scheduled for completion in 2001.

Some general information on the lakes surveyed during 1997 is compiled in Table 1. Figure 1 depicts the locations of the 33 lakes visited during 1997. Figure 2 depicts the locations of all currently active sites in the Lake and Wetland Monitoring Program. In addition to routine lake monitoring, eleven public lakes, streams, and private ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to define all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the city of Herington, Kansas, has jurisdiction over two lakes. The older lake is called Herington City Lake while the newer lake is called Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is sampled once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations: (1) Is there recent data available (within the last 3-4 years)?; (2) Is the lake showing indications of pollution that require enhanced monitoring?; or (3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as "ecoregional" reference sites.

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of inorganic chemistry (basic anions and cations), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, Kjeldahl nitrogen, and phosphorus), and metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium,

Table 1. General Information Pertaining to Lakes Surveyed in 1997.

Lake	Basin	Authority	PWS(*)	Last Surveyed
Atchison Co. Lake	KR	County		1996
Atchison Co. SFL	MO	State		1987
Bourbon Co. SFL	MC	State		1994
Brown Co. SFL	MO	State		1989
Cedar Bluff Lake	SS	Federal		1994
Centralia Lake	KR	City		1996
Clinton Lake	KR	Federal	*	1996
Cowley Co. SFL	LA	State		1993
Eureka Lake	VE	City	*	1991
Gridley City Lake	NE	City		1991
Hamilton Co. SFL	UA	State		new
Hillsdale Lake	MC	Federal	*	1996
Kanopolis Lake	SS	Federal	*	1994
Kingman Co. SFL	LA	State		1987
Leavenworth Co. SFL	KR	State		1989
Marion Co. Lake	NE	County		1993
McPherson Co. SFL	SS	State		1993
Milford Lake	KR	Federal	*	1996
Mission Lake	KR	City	*	1996
Montgomery Co. SFL	VE	State		1994
Mound City Lake	MC	City	*	1994
Neosho Co. SFL	NE	State		1994
Osage Co. SFL	MC	State		1993
Perry Lake	KR	Federal	*	1996
Strowbridge Reservoir	KR	City	*	1993
Tuttle Creek Lake	KR	Federal	*	1996
Wabaunsee Co. Lake	KR	County	*	1993
Webster Lake	SO	Federal		1994
Wellington City Lake	LA	City	*	1993
Wilson Lake	SS	Federal		1994
Winfield City Lake	WA	City	*	1993
Woodson Co. SFL	VE	State		1987
Wyandotte Co. Lake	MO	County		1993

KR=Kansas/Lower Republican, LA=Lower Arkansas, MC=Marais des Cygnes, MO=Missouri, NE=Neosho, SO=Solomon, SS=Smoky Hill/Saline, UA=Upper Arkansas, VE=Verdigris, and WA=Walnut.

Figure 1. Locations of the 33 lake and wetland sites visited during 1997 by the KDHE Lake and Wetland Monitoring Program.

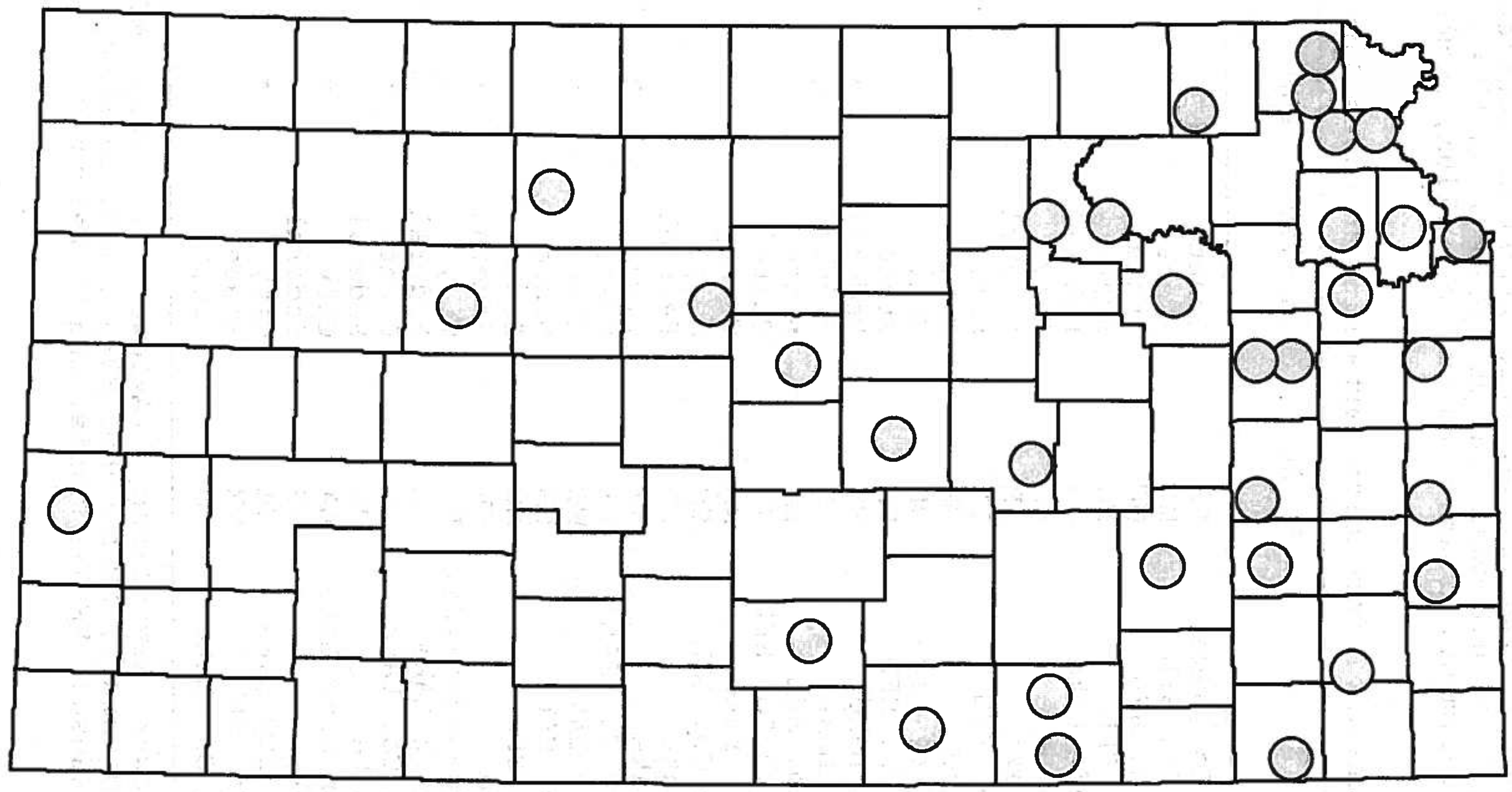
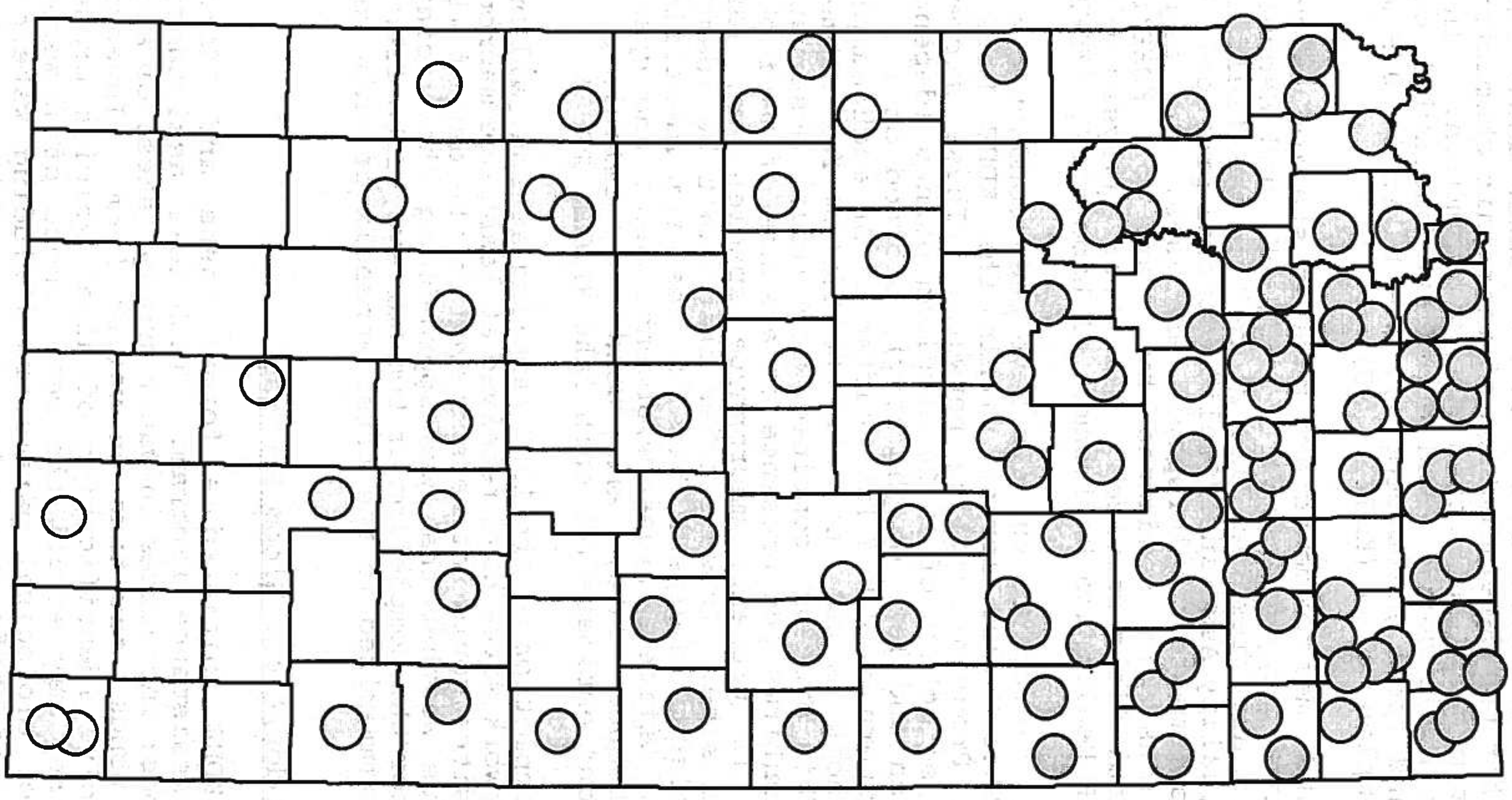


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5-to-1.0 meters above the lake substrate for the determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate bacterial samples (fecal coliform and fecal streptococci), are taken at 0.5 meters at the primary sampling area (KDHE, 1995).

At each lake, measurements are made at station 1 for temperature and dissolved oxygen profiles, field pH, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE Quality Assurance/Quality Control protocols (KDHE, 1995). Field measurements, chlorophyll analyses, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KDHE, 1995).

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program sampling network. These surveys initially entail the selection of 10-20 sampling points (depending on total surface area and lake morphometry), plotted on a field map in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Those species that can't be identified in the field are placed in plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and species specific presence/absence data, are used to calculate a "percent distribution" estimate for each lake (KDHE, 1995).

With the completion of the 1997 sampling season, all but two of the planned network sites have received at least one macrophyte survey. These two sites could not be surveyed on the day of visitation due to dangerous weather that was approaching the vicinity. Rather than wait for the completion of two surveys, data from the other 88 lakes are summarized in the first appendix of this report.

Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied form. Investigations may simply involve identification of algal species present within a lake, or they may entail the measurement of numerous physical, chemical, or biological parameters including watershed land use analysis to identify nonpoint pollution sources. Investigations are generally initiated at the request of treatment plant personnel, local authorities, or personnel at the KDHE District Offices. While lakes used as public water supplies are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both streams and lakes, are accepted for analysis.

RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) remains a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 1997 lakes, previous TSI scores for lakes with past data, and an indication of the extent that individual lakes were dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll TSI scores are based on the planktonic algal community, production due to macrophyte beds is not reflected in those scores. The system used to assign trophic state, based on the TSI score, is given below. Table 2 provides dual trophic state designations for those lakes possessing abundant macrophyte communities. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 30%.

TSI score of 0-39 = Oligo-Mesotrophic = O/M.

> O/M = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a = zero-to-2.5 ug/L.

TSI score of 40-49 = Mesotrophic = M.

> M = A lake with only a moderate planktonic algal community. Chlorophyll-a = 2.51-to-7.2 ug/L.

TSI score of 50-63 = Eutrophic = E.

> E = A lake with a large planktonic algal community. Chlorophyll-a = 7.21-to-30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic = SE (Chl-a = 7.21-to-12.0 ug/L),
TSI = 55-59 = eutrophic (i.e., fully eutrophic) = E (Chl-a = 12.1-to-20.0 ug/L),
TSI = 60-63 = very eutrophic = VE (Chl-a = 20.1-to-30.0 ug/L).

TSI score of 64 or greater = Hypereutrophic = H.

H = A lake with a very large planktonic algal community. Chlorophyll-a = >30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic (Chl-a = 30.0-to-55.9 ug/L),
TSI = >=70 = upper hypereutrophic (Chl-a >= 56 ug/L).

TSI score not relevant = Argillotrophic = A.

In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of an algae community. In such cases, nutrient availability remains high, but is not fully translated into biological productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal production (macrophytic growth is normally absent from such lakes), may be called "argillotrophic" (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronic high turbidity, or may only experience sporadic, but frequent, periods of dis-equilibria following storm events that create "over flows" of runoff at the lake surface.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin-corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6-(2.04-0.68LOG_e(C))/LOG_e(2)).$$

The composition of the algal community often gives a better ecological picture of a lake than relying solely on a trophic state classification. Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 1997. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green species, while those dominated by diatom communities may not be so enriched. Certain species of blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems, when present in large numbers, in lakes or streams that serve as public drinking water sources.

Table 4 presents biovolume data for the 33 lakes surveyed during 1997. When compared to cell count data, such data are useful in determining which species or algal groups actually exert the strongest ecological impact on a lake.

Table 2. Current and past TSI scores, and trophic state classifications for 1997. The abbreviations used previously for trophic state levels (O/M, M, SE, E, VE, H, and A) apply here. An asterisk appearing after the name of a lake denotes that the lake was macrophyte dominated. In such a case, the 1997 trophic classification is adjusted, and the adjusted classification is given in parentheses. Previous TSI scores are based only on algal chlorophyll-a levels.

Lake	1997 TSI	& Status	Previous Status
Atchison Co. Lake	55.3	E	A
Atchison Co. SFL*	56.3	E (VE)	H
Bourbon Co. SFL	57.2	E	M
Brown Co. SFL*	69.7	H (H)	VE
Cedar Bluff Lake	45.5	M	VE
Centralia Lake*	64.6	H (H)	H
Clinton Lake	53.4	E	SE
Cowley Co. SFL	48.4	M	SE
Eureka Lake	51.9	SE	E
Gridley City Lake	39.8	M	VE
Hamilton Co. SFL*	55.1	E (VE)	unknown
Hillsdale Lake	65.0	H ***	E ***
Hillsdale Lake (sta. 1)	51.5	SE	-
Kanopolis Lake	54.0	SE	M
Kingman Co. SFL*	41.4	M (SE)	unknown
Leavenworth Co. SFL*	52.7	E (VE)	E
Marion Co. Lake	58.5	E	SE
McPherson Co. SFL	66.3	H	H
Milford Lake	51.1	SE	M
Mission Lake	67.0	H	A
Montgomery Co. SFL	64.1	H	VE
Mound City Lake*	54.3	SE (E)	H
Neosho Co. SFL*	71.3	H (H)	H
Osage Co. SFL	46.0	M	SE
Perry Lake	59.9	E	SE
Strowbridge Reservoir	57.7	E	M
Tuttle Creek Lake	44.7	A	A
Wabaunsee Co. Lake	47.4	M	M
Webster Lake	52.5	SE	E
Wellington City Lake	48.3	A	E (A)
Wilson Lake	46.8	M	M
Winfield City Lake	53.3	SE	SE
Woodson Co. SFL	42.9	M	M
Wyandotte Co. Lake	48.3	M	M

*** Hillsdale Lake represents a special case as the whole-lake TSI is the mean of three individual stations within the lake. On average, this lake sits on the boundary between slightly and fully eutrophic. This lake will be discussed individually later in the report.

Table 3. Algal communities present in the 1997 lakes at the time of sampling. "Other," in the far right column, refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellates. Percentages may not add to exactly 100 due to rounding.

Lake	Total Count (cells/mL)	Percent Composition green	bluegreen	diatoms	other
Atchison Co. Lake	7,623	24	56	8	12
Atchison Co. SFL	27,972	<1	72	27	<1
Bourbon Co. SFL	7,560	40	10	46	4
Brown Co. SFL	101,966	0	95	5	0
Cedar Bluff Lake	1,953	74	0	23	3
Centralia Lake	41,265	0	100	0	0
Clinton Lake	7,371	13	75	7	5
Cowley Co. SFL	21,830	17	83	0	<1
Eureka Lake	1,985	62	4	0	34
Gridley City Lake	504	76	0	7	17
Hamilton Co. SFL	21,861	2	85	11	2
Hillsdale Lake Sta.1*	3,717	26	40	32	2
Hillsdale Lake Sta.2*	8,379	12	38	14	36
Hillsdale Lake Sta.3*	2,709	15	34	42	9
Kanopolis Lake	2,205	68	0	26	6
Kingman Co. SFL	1,008	87	0	0	13
Leavenworth Co. SFL	9,923	2	99	0	0
Marion Co. Lake	9,923	10	79	5	6
McPherson Co. SFL	15,908	66	0	12	22
Milford Lake	7,277	10	82	8	<1
Mission Lake	47,250	11	65	22	2
Montgomery Co. SFL	34,493	<1	99	0	<1
Mound City Lake	7,907	29	48	21	2
Neosho Co. SFL	79,632	14	85	<1	1
Osage Co. SFL	1,008	66	0	29	5
Perry Lake	9,167	36	29	24	11
Strowbridge Reservoir	3,654	50	0	17	33
Tuttle Creek Lake	2,489	28	0	65	7
Wabaunsee Co. Lake	4,536	37	62	0	1
Webster Lake	4,694	51	30	12	7
Wellington City Lake	2,709	32	58	2	8
Wilson Lake	819	69	0	23	8
Winfield City Lake	2,300	71	0	11	8
Woodson Co. SFL	1,134	55	12	20	13
Wyandotte Co. Lake	4,284	25	67	5	3

* Hillsdale Lake represents a special case due to the use of three primary sampling stations. It will be discussed individually later in this report.

Table 4. Algal biovolumes calculated for the 1997 lakes at the time of sampling. "Other," in the far right column, refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellates. Percentages may not add to exactly 100 due to rounding. Biovolume units are calculated in mm^3/L, and expressed as parts-per-million (ppm).

Lake	Total Biovolume (ppm)	Percent Composition green	bluegreen	diatoms	other
Atchison Co. Lake	4.81	20	18	17	45
Atchison Co. SFL	16.76	<1	53	42	5
Bourbon Co. SFL	12.12	34	10	45	11
Brown Co. SFL	44.79	0	63	37	0
Cedar Bluff Lake	1.93	22	0	21	57
Centralia Lake	11.20	0	100	0	0
Clinton Lake	6.53	5	48	16	31
Cowley Co. SFL	3.09	35	57	0	8
Eureka Lake	4.10	21	<2	0	77
Gridley City Lake	0.67	51	0	<1	49
Hamilton Co. SFL	17.47	3	36	52	9
Hillsdale Lake Sta.1*	3.56	15	8	65	12
Hillsdale Lake Sta.2*	29.53	2	4	11	83
Hillsdale Lake Sta.3*	3.73	8	5	50	37
Kanopolis Lake	3.66	33	0	53	14
Kingman Co. SFL	1.09	75	0	0	25
Leavenworth Co. SFL	4.93	3	97	0	0
Marion Co. Lake	7.53	7	61	14	18
McPherson Co. SFL	10.65	38	0	17	45
Milford Lake	3.06	14	43	41	2
Mission Lake	33.32	4	27	61	8
Montgomery Co. SFL	30.98	<1	91	0	9
Mound City Lake	5.45	33	5	54	8
Neosho Co. SFL	16.86	23	68	1	8
Osage Co. SFL	0.60	41	0	38	21
Perry Lake	14.81	9	7	61	23
Strowbridge Reservoir	4.36	28	0	15	57
Tuttle Creek Lake	3.66	6	0	85	9
Wabaunsee Co. Lake	2.53	52	45	0	3
Webster Lake	3.51	37	8	3	52
Wellington City Lake	1.26	23	37	2	38
Wilson Lake	2.43	50	0	10	40
Winfield City Lake	2.00	36	0	25	39
Woodson Co. SFL	1.18	36	5	32	27
Wyandotte Co. Lake	2.39	28	5	38	29

* Hillsdale Lake represents a special case which, as stated before, will be discussed individually later in this report.

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 33 lakes surveyed in 1997. Eleven lakes displayed increases in lake trophic state (about 33%). Twelve lakes appeared to remain stable over time (about 36%). About 24% of the lakes surveyed in 1997 show improvement (lowered trophic state) since their last surveys, while two lakes had insufficient data for examining trends.

As shown in Table 6, all eleven lakes surveyed for macrophytes had detectable communities. In these lakes, the common plant species were various forms of pondweed (Potamogeton spp.), water naiad (Najas guadalupensis), coontail (Ceratophyllum demersum), and stonewort algae (Chara spp.).

Appendix A discusses macrophyte data for 88 of the lakes in the KDHE Lake and Wetland Monitoring Program Network, which have been surveyed over the 1991-to-1997 time period. Included in this discussion are geographic trends for individual species as well as for total macrophyte abundance in lakes.

Lake Stratification

Stratification is a natural process that may occur in any standing body of water, whether that waterbody is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (heat energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (hypolimnion) remains near the bottom of the lake while the upper layer (epilimnion) develops a higher ambient temperature. The middle layer (metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion.

Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to be depleted of oxygen and unavailable as habitat for fish and other aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. This, typically, fall phenomenon is called "lake turnover."

Table 5. Trends over time for lake trophic state classification within each major river basin in Kansas. Two of the lakes are not included, Hamilton Co. SFL because it had not been surveyed before 1997, and Kingman Co. SFL due to the long time period since it was last surveyed.

Basin	Number of Lakes Constant	Improving	Degrading
Kansas/Lower Republican	5	0	5
Lower Arkansas	1	1	0
Marais des Cygnes	0	2	2
Missouri	1	1	1
Neosho	1	1	1
Solomon	0	1	0
Smoky Hill/Saline	2	1	1
Verdigris	1	1	1
Walnut	1	0	0
Totals	12	8	11

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic waters with epilimnetic waters that are lower in nutrients and richer in dissolved oxygen. This often results in explosive algal growth, lowering of overall lake dissolved oxygen levels, sudden fishkills, and often imparts objectionable odors to the lake water and tastes or odors to drinking water produced from the lake. Therefore, this lake process is an important facet of lake management, the ability of the waterbody to support aquatic life, and the ability of the waterbody to support sport fisheries.

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing lake sediment quality, and the inflow of materials from the watershed.

Sediment re-release of materials, and water quality impact at turnover, would be most pronounced in a deep, moderate-to-small sized lake, with abundant protection from the winds, shallow thermocline, and a history of high pollutant loads from the watershed. For the majority of our larger lakes in Kansas, built on major rivers with dependable inflows, stratification tends to be

Table 6. Macrophyte community structure in 11 of the lakes surveyed during 1997. Macrophyte community in these surveys refers to submersed and floating-leaved aquatic plants, but not to the emergent shoreline community. The percent species cover is the abundance estimate for each documented species (Note: due to overlap in species cover, the percentages under community composition may not equal the percent total cover.).

Lake	% Total Cover	% Species Cover and Community Composition	
Atchison Co. SFL	80%	80%	*Ceratophyllum demersum*
		70%	*Potamogeton foliosus*
		40%	*Potamogeton pectinatus*
		40%	*Najas guadalupensis*
		20%	*Potamogeton* sp.
Bourbon Co. SFL	10%	10%	*Chara globularis*
Brown Co. SFL	90%	90%	*Potamogeton foliosus*
		30%	*Ceratophyllum demersum*
		10%	*Potamogeton pectinatus*
Centralia Lake	75%	70%	*Potamogeton foliosus*
		50%	*Potamogeton pectinatus*
		10%	*Potamogeton nodosus*
		10%	*Najas guadalupensis*
Hamilton Co. SFL	100%	100%	*Potamogeton pectinatus*
		90%	*Chara globularis*
		30%	*Ceratophyllum demersum*
Kingman Co. SFL	100%	100%	*Potamogeton pectinatus*
		100%	*Najas guadalupensis*
		40%	*Potamogeton nodosus*
		40%	*Nelumbo* sp.
Leavenworth Co. SFL	60%	53%	*Potamogeton crispus*
		40%	*Potamogeton pusillus*
		33%	*Potamogeton nodosus*
		27%	*Najas guadalupensis*
		7%	*Potamogeton pectinatus*
Montgomery Co. SFL	25%	25%	*Zanichellia palustris*
Mound City Lake	80%	73%	*Potamogeton illinoensis*
		47%	*Najas guadalupensis*
		40%	*Ceratophyllum demersum*
		40%	*Chara zeylanica*
		7%	*Potamogeton pectinatus*
		7%	*Potamogeton foliosus*
Neosho Co. SFL	50%	50%	*Najas guadalupensis*
		33%	*Potamogeton foliosus*
		7%	*Chara globularis*
Woodson Co. SFL	33%	33%	*Najas guadalupensis*
		20%	*Potamogeton nodosus*
		15%	*Chara zeylanica*
		7%	*Potamogeton pusillus*

intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in larger Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents this data. Any temperature change greater than -1.0 degree Celsius per meter depth is considered evidence of strong thermal stratification (Hutchinson, 1957; Wetzel, 1983), although temperature changes may be less pronounced during the initiation phase of stratification. Presence of a significant oxycline is also used to verify stratification. Many of the larger lakes, created by impounding major rivers, exhibit polymictic behavior. In these lakes, stratification may never be very strong, and the water column may stratify and de-stratify several times during the summer, if at all.

Contact Recreation and Fecal Coliform Bacterial Counts

From 1992-to-1995, bacterial samples were collected at swimming beaches, or other appropriate near-shore sites, rather than at the primary sampling station in the lake. In 1996, bacterial samples were again collected from the same deep-water station used for other chemical and biological sampling. This change was precipitated by several arguments. First, as bacterial sampling is most strongly associated with contact recreation (swimming and skiing), and contact recreation is not limited to swimming beaches, a more whole-lake assessment was appropriate. Second, the sampling frequency possible for this program is not adequate to truly characterize a localized swimming beach area. Third, many larger lakes tended to have multiple beaches which outstripped scheduled laboratory capacity. Fourth, beach sampling should be the responsibility of the entity that administers the beach property. Such administrative entities are in a much better position to conduct adequate sampling, in terms of collection frequency and number of samples.

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacteria counts should only occur in the open water of a lake if 1) there has been a recent pollution event, or 2) there is a chronic input of bacteria-laced pollution. Given such a setting, a single set of bacterial samples should be reasonably representative of whole-lake bacterial water quality at the time of the survey.

Table 8 presents the bacterial data collected during the 1997 sampling season. All counts are compared to the 200 colonies/100 mL standard for contact recreation within the Kansas Surface Water Quality Standards (KDHE, 1994).

Table 7. Lake and wetland stratification status for the 33 sites surveyed during 1997.

Lake	Date Sampled	Temperature Decline Rate (degrees/meter)	Dissolved Oxygen Decline Rate (mg/L per meter)	Thermocline Depth (meters)	Maximum Depth Recorded (meters)
Atchison Co. Lake	July 8	na	na	none likely	1.5
Atchison Co. SFL	July 9	-2.05	-0.94	2-4	10.0
Bourbon Co. SFL	June 9	-1.00	-0.98	4-5	10.0
Brown Co. SFL	July 7	-2.50	-2.43	1-4	4.5
Cedar Bluff Lake	June 24	-0.47	-0.40	6-8	19.0
Centralia Lake	July 7	-0.62	-1.35	3-4	6.5
Clinton Lake	July 16	-0.33	-0.96	3-4	12.0
Cowley Co. SFL	August 4	-1.56	-0.92	3-4	9.0
Eureka Lake	June 9	-0.50	-0.88	2-3	8.0
Gridley City Lake	June 9	-0.67	-1.83	2-3	3.0
Hamilton Co. SFL	August 12	na	na	unknown	2.0
Hillsdale Lake Sta.1	July 15	-0.92	-0.89	6-7	12.0
Hillsdale Lake Sta.2	July 15	-0.78	-1.26	6-7	9.0
Hillsdale Lake Sta.3	July 15	-0.63	-1.24	7-8	8.0
Kanopolis Lake	June 23	-0.10	-0.26	none present	10.0
Kingman Co. SFL	August 19	-2.50	-6.70	0-0.5	2.0
Leavenworth Co. SFL	July 21	-1.43	-0.56	4-6	14.0
Marion Co. Lake	July 23	-1.15	-0.86	4-6	10.0
McPherson Co. SFL	June 16	-1.08	-1.12	2-3	6.0
Milford Lake	July 14	-0.47	-0.41	13-15	18.0
Mission Lake	July 8	-0.67	-2.25	3-4	4.5
Montgomery Co. SFL	June 10	-1.38	-1.25	2-3	6.5
Mound City Lake	July 29	-1.09	-1.18	2-3	5.5
Neosho Co. SFL	July 28	-1.56	-1.11	2-3	8.0

Table 7 continued. Lake and wetland stratification status for the 33 sites surveyed during 1997.

Lake	Date Sampled	Temperature Decline Rate (degrees/meter)	Dissolved Oxygen Decline Rate (mg/L per meter)	Thermocline Depth (meters)	Maximum Depth Recorded (meters)
Osage Co. SFL	June 18	-1.45	-0.73	3-4	11.0
Perry Lake	July 16	-0.46	-0.70	7-8	14.0
Strowbridge Reserv.	June 18	-0.94	-1.04	2-3	9.0
Tuttle Creek Lake	July 14	-0.28	-0.32	none present	16.0
Wabaunsee Co. Lake	June 30	-1.00	-0.95	4-6	8.0
Webster Lake	June 24	-0.54	-0.66	8-9	12.0
Wellington CL	August 4	-0.60	-1.22	3-5	5.0
Wilson Lake	June 24	-0.44	-0.44	11-13	18.0
Winfield City Lake	August 4	-0.84	-0.66	6-8	12.5
Woodson Co. SFL	July 28	-1.50	-0.51	3-5	14.0
Wyandotte Co. Lake	July 21	-1.42	-0.58	5-6	13.0

na = Indicates that boat access, wind conditions, shallowness, or equipment problems prevented taking profile data or made its acquisition superfluous.

Eight lakes, out of the 33 surveyed, had fecal coliform bacterial counts that averaged above the detection limit. Only two lakes exceeded the 200 colonies/100 mL criteria for contact recreation (average of duplicate samples). These two lakes were McPherson Co. SFL (mean = 235 colonies/100 mL) and Neosho Co. SFL (mean = 300 colonies/100 mL).

In the case of McPherson Co. SFL, there had been recent rain and runoff, within the previous two days, that could have resulted in a temporary increase in ambient bacteria levels. Past watershed surveys of the McPherson Co. SFL drainage show that abundant pasture area exists immediately upstream of the wildlife area boundary, including at least one animal confinement/feedlot operation. For Neosho Co. SFL, a number of small animal confinement/feedlot areas exist just upstream of the lake, although elevated bacteria levels may have been the result of lake maintenance work that was being conducted in an arm of the lake near the dam. This work could have allowed resuspension of some fine sediment materials and attached bacteria into the open waters of the lake.

In the case of both lakes, contact recreation is not a current use. Therefore, exceedence of the 200 colonies/100 mL criterion does not constitute a water quality problem in the eyes of existing State regulations. Both lakes currently host non-contact recreation uses, and both complied with the applicable non-contact criterion of 2,000 colonies/100 mL.

<u>Limiting Nutrients and Physical Parameters</u>

The determination of which nutrient, or physical characteristic, "limits" phytoplankton production is of primary importance in lake management. If certain features can be identified, which exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

The concept of limiting nutrients, or limiting factors, is often difficult for the layman to grasp. The following analogy is provided in an attempt to clarify the concept:

> A person is given 10 spoons, 9 knives, and 5 forks. They are then asked to place sets of utensils at each seat at a large table. Further, only complete sets of utensils are to be placed, with a complete set including all three utensils. The question is, "What utensil is the limiting factor?"
>
> In this example, the number of forks available "limits" the number of place settings that can be made. So, "forks" become the limiting factor for this scenario.

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 33 lakes surveyed during 1997. Note that these counts are based on one time grab samples taken during the week, not during the weekends which generally constitute higher use periods. All units are in "number of colonies per 100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Atchison Co. Lake	near dam	<10
Atchison Co. SFL	open water	<10
Bourbon Co. SFL	open water	<10
Brown Co. SFL	open water	<10
Cedar Bluff Lake	open water	<10
Centralia Lake	open water	<10
Clinton Lake	open water	<10
Cowley Co. SFL	open water	<10
Eureka Lake	open water	<10
Gridley City Lake	open water	<10
Hamilton Co. SFL	near dam	>80
Hillsdale Lake *	open water	<10
Kanopolis Lake	open water	<10
Kingman Co. SFL	open water	<2
Leavenworth Co. SFL	open water	40
Marion Co. Lake	open water	<10
McPherson Co. Lake	open water	235
Milford Lake	open water	<10
Mission Lake	open water	10
Montgomery Co. SFL	open water	<10
Mound City Lake	open water	37
Neosho Co. SFL	open water	300
Osage Co. SFL	open water	20
Perry Lake	open water	<10
Strowbridge Reservoir	open water	<10
Tuttle Creek Lake	open water	<10
Wabaunsee Co. Lake	open water	<10
Webster Lake	open water	<10
Wellington City Lake	open water	<10
Wilson Lake	open water	<10
Winfield City Lake	open water	<10
Woodson Co. SFL	open water	22
Wyandotte Co. Lake	open water	<10

* Count represents the mean count of all three sampling stations on Hillsdale Lake.

In a lake ecosystem, the level of algal production is the "place setting," while plant nutrients and light availability are the "spoons, forks, etc." Common factors that limit algal production in lakes are the levels of available nutrients (primarily phosphorus and nitrogen) and the amount of light available to power photosynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon, iron, temperature, and/or trace elements (e.g., molybdenum or vitamins).

Nutrient ratios are commonly employed in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical nutrients. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 12 indicate phosphorus limitation. Conversely, TN/TP ratios below 7 indicate nitrogen limitation. Ratios of 7-to-12 indicate that both, or neither, of these major plant nutrients may be limiting phytoplankton production (Wetzel, 1983).

Table 9 presents limiting factor determinations for the lakes surveyed during 1997. It should be kept in mind that these determinations reflect the time of sampling (which is chosen to reflect "average" conditions during the summer months to the extent possible) but may not apply to other times of the year. There is, however, always the chance that conditions during one survey will differ from conditions during past surveys, despite efforts to sample during times representative of "normal" conditions. If such conditions are suspected, they will be noted in Table 9.

As can be seen from the data in Table 9, phosphorus is the primary limiting factor for lakes surveyed during the summer of 1997. Twenty of the 33 lakes (61%) were primarily phosphorus limited. Three lakes (9%) were limited primarily by nitrogen. Another five lakes (15%) were identified as likely co-limited by phosphorus and nitrogen. Light limitation was deemed a possibility at seven lakes (21%) but clearly indicated at only two (6%). An additional two lakes (6%) appeared to be inordinately influenced by dense macrophyte beds. Gridley City Lake's limiting factors remain a mystery, based on the conflicting metric values.

Four additional metrics are considered, in this report, to help determine the relative roles of light and nutrient limitation for lakes in Kansas. These metrics, and their description, follow (Walker, 1986).

1) Non-Algal Turbidity = $(1/SD)-(0.025m^2/mg*C)$,

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3.

Non-algal turbidity values of $<0.4^{-m}$ tend to indicate <u>very</u> low levels of suspended silt and/or clay, while values $>1.0^{-m}$ indicate that inorganic particles are important in creating turbidity. Values between 0.4 and 1.0^{-m} describe a range where inorganic turbidity assumes greater importance as the value increases, but would not assume a significant limiting role until values exceed 1.0^{-m}.

Table 9. Limiting factor determinations for the 33 surveyed lakes in 1997, including TN/TP ratios and other metrics. Factors are listed in descending order of importance (P = phosphorus, N = nitrogen, and L = light).

Lake	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use	Limiting Factors
Atchison Co. Lake	13.2	2.55	0.73	4.34	0.12	P=N>L
Atchison Co. SFL	20.9	0.49	1.68	16.44	0.46	P
Bourbon Co. SFL	6.7	0.62	2.13	15.15	0.51	N>P
Brown Co. SFL	24.4	<0.05	<0.05	51.30	0.83	P
Cedar Bluff Lake	9.7	0.60	3.60	6.44	0.15	P=N>L
Centralia Lake	16.6	0.25	0.65	30.40	0.43	P
Clinton Lake	16.0	0.41	1.60	15.38	0.34	P
Cowley Co. SFL	6.0	0.47	1.52	9.84	0.41	N=P
Eureka Lake	10.5	0.78	2.32	8.80	0.29	N=P
Gridley City Lake	26.3	0.47	0.55	4.66	0.10	?
Hamilton Co. SFL	11.2	<0.94	0.57	9.84	0.06	N>P=L*
Hillsdale Lake Sta. 1	42.0	0.71	3.27	8.91	0.41	P>L
Hillsdale Lake Sta. 2	14.8	<0.05	<0.05	50.70	0.99	P
Hillsdale Lake Sta. 3	39.5	0.68	2.19	8.57	0.37	P
Hillsdale Lake (mean)	32.1	0.22	1.01	31.73	0.80	P
Kanopolis Lake	5.6	1.06	4.13	8.18	0.27	N=P>L
Kingman Co. SFL	26.5	<0.42	0.26	6.10	0.09	P*
Leavenworth Co. SFL	70.5	0.22	0.89	21.01	0.96	P
Marion Co. Lake	11.0	0.40	1.38	20.64	0.34	P>N
McPherson Co. SFL	11.1	1.55	3.73	15.18	0.39	P>N>L
Milford Lake	9.2	0.71	4.13	8.86	0.07	N>P=L
Mission Lake	20.1	1.20	2.24	18.41	0.58	P
Montgomery Co. SFL	19.3	0.24	0.61	30.50	0.87	P
Mound City Lake	14.4	0.72	1.61	11.20	0.37	P
Neosho Co. SFL	16.1	0.41	1.21	31.90	0.58	P
Osage Co. SFL	11.9	0.65	2.22	6.31	0.49	P>N
Perry Lake	45.6	0.30	1.36	24.81	0.79	P

Table 9. Continued.

Lake	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use	Limiting Factors
Strowbridge Reservoir	16.6	1.03	3.31	11.13	0.44	P>L
Tuttle Creek Lake	12.8	2.75	14.98	1.47	0.02	L
Wabaunsee Co. Lake	27.3	0.42	1.24	9.99	0.29	P
Webster Lake	12.5	0.43	1.94	14.03	0.31	P
Wellington City Lake	5.5	3.18	6.55	1.83	0.05	L
Wilson Lake	24.5	0.54	3.13	7.80	0.26	P>L
Winfield City Lake	2.7	0.41	1.61	15.23	0.34	N>P
Woodson Co. SFL	18.8	0.33	1.35	8.52	0.24	P
Wyandotte Co. Lake	18.5	0.38	1.49	11.50	0.61	P

* Lakes likely dominated by macrophyte mediated processes.

Expected Lake Condition	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use
Phosphorus Limiting	>12				>0.4
Nitrogen Limiting	<7				<0.13
Light/Flushing Limited		>1.0	>6	<6	<0.13
High Algae-Nutrient Response		<0.4	<3	>16	>0.4
Low Algae-Nutrient Response		>1.0	>6	<6	<0.13
High Inorganic Turbidity		>1.0	>6	<6	
Low Inorganic Turbidity		<0.4	<3	>16	
High Light Availability			<3	>16	
Low Light Availability			>6	<6	

2) Light Availability in the Mixed Layer = Z_{mix}*Turbidity,

where Z_{mix} = depth of the mixed layer, in meters, and Turbidity = the previously mentioned Non-Algal Turbidity.

Values below 3 indicate abundant light, within the mixed zone of the lake, and a high algal response to nutrients. Values Above 6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Turbidity = Chl-a*Secchi Disk Depth,

where Chl-a = algal chlorophyll-a in mg/m^3 and Secchi depth in meters.

Values less than 6 indicate inorganic turbidity dominates light extinction in the water column and a weak algal response to nutrients. Values above 16 indicate the opposite.

4) Algal Use of Phosphorus Supply = Chl-a/TP,

where Chl-a = algal chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3.

Values less than 0.13 indicate a low algal response to phosphorus, indicating that nitrogen or light limitation may be important. Values above 0.4 indicate the opposite, while the range in-between suggests various levels of moderate algae-phosphorus response.

In identifying the limiting factors for lakes during 1997, primary importance was given to the 1997 metrics. However, past Secchi depth and chlorophyll-a data were also used in comparison to 1997 data. Additionally, mean and total lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidities may have little real impact from that turbidity if the entire water column can rapidly circulate, bringing algae quickly back to the surface and sunlight.

<u>Surface Water Exceedences of State Water Quality Criteria</u>

All numeric and narrative water quality criteria referred to in this section are taken from Chapter 28 of the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA 1972, 1976; KDHE, 1994) for ambient waters and finished drinking water. Metals criteria are influenced strongly by the promulgation of criteria for dissolved metals under the EPA National Toxics Rule. Copies of the Standards may be obtained from the Bureau of Water, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620.

Tables 11, 12 and 13 present documented exceedences of surface water quality criteria and goals during the 1997 sampling season. These data were generated by comparison of a computer data retrieval, for 1997 Lake and Wetland Monitoring Program ambient data, to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth above 3.0 meters were used to document standards violations, as a majority of those samples collected from below 3.0 meters are from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities (compared to overlying waters), do not generally pose a significant water quality problem for the lake as a whole.

Eutrophication criteria, in the Kansas Surface Water Quality Standards are narrative rather than numeric. This is partially due to the fact that the trophic state of any individual lake reflects a number of site-specific and regional environmental characteristics, combined with pollutant inputs from its watershed. However, lake trophic state does exert a documented impact on various lake uses. The system on the following page (Table 10) has been developed over the past eight years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). These trophic state/use support combinations are joined with the site-specific lake trophic state designations to determine expected use support levels at each lake.

With respect to the aquatic life support use; atrazine, eutrophication, and low dissolved oxygen (within the first 3.0 meters depth) comprised the primary water quality concerns during 1997 (Table 11). Seven lakes exhibited trophic states high enough to impair normal uses, including long and short-term aquatic life support. Three lakes exhibited atrazine herbicide levels that exceeded the interim chronic aquatic life support criterion (3.0 ppb). Eleven lakes had dissolved oxygen concentrations, within the top 3.0 meters, below the minimum criterion. Only six of these instances related to acute aquatic life criteria, and most were due to very high lake trophic states.

Eutrophication exceedences are primarily due to excessive nutrient inputs from the watersheds that drain to these lakes. Dissolved oxygen problems may be due to trophic status, in part, but were also observed in lakes without excessive eutrophication. In these cases, the low oxygen resulted from conditions that led to shallow stratification. Atrazine exceedences resulted from agricultural nonpoint source runoff.

Table 10. Lake use support determination based on lake trophic state.

Use	Trophic State Code A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life	X	F	F	F	P	P	N	N
Drinking Water Supply	X	F	F	P	P	N	N	N
Contact Recreation	X	F	F	P	P	N	N	N
Non-Contact Recreation	X	F	F	F	P	P	N	N
Livestock Water Supply	X	F	F	F	P	P	N	N
Irrigation	X	F	F	F	P	P	N	N
Groundwater Recharge	not generally applicable							
Food Procurement	applicable, but not directly							

BG = bluegreen algae are dominant (50%+ as cell count and/or 33%+ as biovolume)

F = full support of the use
P = partial support of the use
N = use is not adequately supported
X = use support assessed based on nutrient load rather than algal biomass

A = argillotrophic (high turbidity limits algae production)
M = mesotrophic (includes the class O/M, oligo-mesotrophic), TSI = zero-to-49.9
SE = slightly eutrophic, TSI = 50-to-54.9
E = fully eutrophic, TSI = 55-to-59.9
VE = very eutrophic, TSI = 60-to-63.9
H = hypereutrophic, TSI = 64+

TSI = 64 = chlorophyll-a concentration of 30 ppb
TSI = 70 = chlorophyll-a concentration of 56 ppb

Table 11. Chemical parameters not complying with chronic and acute aquatic life support criteria in lakes surveyed during 1997. Chemical symbols are from the Periodic Table of the Elements. Atz = atrazine. Aquatic life support = ALS. Dissolved oxygen = DO. EN = eutrophication and high nutrient load. Only those lakes with some type of documented water quality problem are included in Tables 11, 12 and 13.

Lake	Chronic ALS				Acute ALS
	pH	DO	Atz	EN	EN
Atchison Co. Lake			x		
Atchison Co. SFL		x			
Brown Co. SFL	x	x		x	x
Centralia Lake			x	x	x
Eureka City Lake		x			
Gridley City Lake		x			
Hillsdale Lake				x	x
Kingman Co. SFL	x	x			
McPherson Co. SFL		x		x	
Mission Lake			x	x	x
Montgomery Co. SFL		x		x	x
Mound City Lake		x			
Neosho Co. SFL		x		x	x
Osage Co. SFL		x			
Strowbridge Res.		x			

Table 12. Exceedences of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 1997. Symbols are taken from the Periodic Table of the Elements. Atz = atrazine, Cl = chloride, SO4 = sulphate, and EN = eutrophication and high nutrient load. Only lakes with documented exceedences are included within the table. An "x" indicates that the exceedence occurred for a use presently existing, or likely in the foreseeable future, at the given lake. An "*" indicates that the exceedence occurred where the indicated use has not yet been determined.

Lake	Water Supply				Irrigation	Livestock Water
	Atz	EN	Cl	SO4	EN	EN
Atchison Co. Lake	*	*				
Atchison Co. SFL		*				
Bourbon Co. SFL		*				
Brown Co. SFL		*			*	*
Cedar Bluff				*		
Centralia City Lake	*	*			*	*
Hamilton Co. SFL		*	*	*		
Hillsdale Lake		x			*	*
Marion Co. Lake		*				
McPherson Co. SFL		*			*	*
Mission Lake	x	x			*	*
Montgomery Co. SFL		*			*	*
Neosho Co. SFL		*			*	*
Perry Lake		x				
Strowbridge Res.		x				
Webster Lake				*		
Wilson Lake			*	*		

Table 13. Exceedences of applicable numeric and narrative water quality criteria for the lakes sampled in 1997, as related to recreational uses. Contact recreation refers to recreational forms that make accidental ingestion of water highly probable. Non-contact recreation does not entail a high likelihood of accidently ingesting lake water. FC = fecal coliform bacteria and EN = eutrophication and nutrient load. An "x" indicates that the exceedence occurred for a use presently existing, or likely in the foreseeable future, at the given lake. An "*" indicates that the exceedence occurred where the indicated use has not yet been determined.

Lake	Contact Recreation FC	Contact Recreation EN	Non-Contact Recreation EN
Atchison Co. Lake		*	
Atchison Co. SFL		*	
Bourbon Co. SFL		*	
Brown Co. SFL		*	x
Centralia Lake		x	x
Hamilton Co. SFL		*	
Hillsdale Lake		x	x
Marion Co. Lake		*	
McPherson Co. SFL	*	*	x
Mission Lake		x	x
Montgomery Co. SFL		*	x
Neosho Co. SFL	*	*	x
Perry Lake		x	
Strowbridge Res.		*	

As shown in Table 12, there were 23 exceedences of drinking water supply criteria during 1997. The majority of these were for eutrophication (14), atrazine (3), and salinity related conditions (6). Examining just those lakes that currently serve as water supplies, exceedences are reduced to five. Most of these five are related to high lake trophic state.

Irrigation use was impaired in seven lakes, due to high lake trophic state, but none of these lakes currently host the irrigation use. Likewise, livestock watering use was impaired at seven lakes, none of which currently host the livestock watering use. Fourteen lakes had high enough trophic status to impair contact recreation (Table 13). Four of these lakes actually have swimming beaches and host the full range of contact recreational activities. High trophic state impaired the non-contact recreational uses of seven lakes during 1997.

In all, 89 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines were documented for Kansas lakes during 1997. Of these, only 22 (25%) related to currently existing consumptive or recreational lake uses, or for acute aquatic life support criteria. The majority were for chronic aquatic life support criteria, or for lakes where the specific consumptive uses are not designated.

Pesticides in Kansas Lakes, 1997

Twenty-one lakes (64% of the total) had detectable levels of pesticides within them during 1997. Table 14 lists these lakes and the pesticides that were detected, along with the level detected and analytical quantification limit. Six different pesticides, and one pesticide degradation by-product, were detected in total.

Atrazine continues to be the most often detected pesticide in Kansas (KDHE, 1991). Atrazine was identified in 19 of the 21 lakes with detectable levels of pesticides. Fifteen lakes had detections of Dual (metolachlor), seven lakes had detections of alachlor, and 13 lakes had detections of deethylatrazine during 1997. In addition, there was a single detection of 2,4-D, one of cyanazine (Bladex), and two of acetochlor (Harness or Surpass).

In all cases, the detection of these pesticides indicates impacts from agricultural nonpoint source pollution. The sites of most concern during 1997, relative to the number of different pesticides detected, were Atchison County Lake, Brown Co. SFL, Centralia Lake, Milford Lake, Mission Lake, Strowbridge Reservoir, and Tuttle Creek Lake. Lakes of most concern, based on pesticide concentrations seen in 1997, include Atchison County Lake, Atchison Co. SFL, Centralia Lake, Milford Lake, and Mission Lake. All of the lakes with specific pesticide concerns are located within either the Kansas/Lower Republican or Missouri River Basins. Of these 21 lakes, only five were at, or above, the 3.0 ug/L water supply criterion for atrazine. Of these five lakes, only two are currently water supplies.

Discussion of Nonpoint Sources of Pollution for Selected Lakes

Seven lakes and wetlands were chosen for further discussion, based on the number and type of surface water quality standards exceedences that were observed. A waterbody was chosen if 1) three, or more, parameters experienced exceedences of chronic criteria of the aquatic life support use, 2) more than one parameter experienced exceedences of acute criteria of the aquatic life support use, 3) more than one parameter exceeded irrigation, water supply, or livestock watering criteria. Each selected lake will be briefly examined to identify the possible causes and sources of its documented water quality problems.

Table 14. Pesticides detected during 1997 in Kansas lakes. All values are in ug/L. Analytical quantification limits are as follows for the seven detected pesticides and degradation by-products: atrazine (Atz) = 0.3 ug/L, metolachlor (Dual) = 0.25 ug/L, alachlor (Ala) = 0.1 ug/L, 2,4-D = 0.8 ug/L, deethylatrazine (deatz) = 0.3 ug/L, cyanazine (Cyan) = 0.5 ug/L, and acetochlor (Acet) = 0.1 ug/L.

Lake	Pesticide						
	Atz	Deatz	Dual	Ala	2,4-D	Cyan	Acet
Atchison Co. Lake	13.00	5.30	4.50	0.24			
Atchison Co. SFL	3.00	0.58	0.97				
Brown Co. SFL	2.30	1.10	0.60			1.50	
Cedar Bluff Lake	0.33						
Centralia Lake	5.40	1.20	2.00	0.54			
Clinton Lake	1.20	0.53	0.39				
Gridley City Lake					2.10		
Hillsdale Lake	2.10	0.97	0.55				
Kanopolis Lake	0.49						
Marion Co. Lake	0.99		0.28				
McPherson Co. SFL	1.90	0.33	1.30				
Milford Lake	3.00	0.34	1.50	0.15			
Mission Lake	3.70	0.88	0.50	0.12			0.29
Neosho Co. SFL	0.43						
Osage Co. SFL	2.00		0.50	0.12			
Perry Lake	2.40	0.62	0.69				
Strowbridge Reserv.	2.10	0.46	0.68	0.18			
Tuttle Creek Lake		1.00	4.00	1.30			0.27
Wellington City Lake	1.90	0.40	1.90				
Winfield City Lake	1.50						
Woodson Co. SFL	0.94						

Wilson Lake and Hamilton Co. SFL both appear to have similar circumstances as regards water quality. Both exist under conditions of low inflow/high evaporation typical of western Kansas, and both have similar water quality concerns related to salinity. Moreover, Hamilton Co. SFL has developed an extensive macrophyte community due to shallow depth and clear baseflow inputs from springs.

Atchison County, Mission, Brown Co. SFL, and Centralia Lakes all appear to receive significant nonpoint source loads for silt, nutrients, and pesticides from cultivated watersheds. Recent lake renovation at Brown Co. SFL has greatly reduced turbidity and siltation, but appears to have allowed extensive macrophyte colonization. As for the previous group of lakes, there is a distinct regional set of water quality concerns based on location.

Additionally, Hillsdale Lake is influenced by excessive nutrient loads from both point source dischargers and various nonpoint agricultural sources. Pesticide loads are also of concern, in terms of both magnitude of occurrence and number of pesticides usually detected. This lake is discussed further in Appendix B.

<u>Taste and Odor/Algae Bloom Investigations and Other Special Investigations in 1997</u>

During the period of October 1, 1996 to October 31, 1997, nine investigations were undertaken within the auspices of the Taste and Odor/Algae Bloom Program. Each will be discussed individually within the remainder of this section. Five of the investigations were related to aesthetic quality (color, foam, etc.), two dealt with fishkill investigations, one dealt with odor complaints, and one dealt with livestock deaths near a pond with unusual aesthetic quality.

On March 12, 1997, algae samples were submitted by the KDHE Southeast District Office after a feedlot lagoon was discharged into Four Mile Creek near Erie, Kansas. The stream samples had a significant pink coloration. Concern was expressed that the water coloration might be due to microbial organisms, which could later cause fishkills or other water quality problems. Examination of the samples revealed little in the way of phytoplankton, but an abundance of ciliated and flagellated protozoa and bacteria was noted. Although the organisms appeared colorless under the microscope, it was proposed by KDHE staff that their sheer numbers were the cause of the pink coloration of the stream. Although the microbiological literature suggested that some lagoon associated bacteria do produce such colorations, other tests on the samples suggested the color may not be due to organic components. Heat treatment of the samples (90-to-100° C for 1 hour) did not appear to degrade or denature the color of the sample. Treatment of the sample with an oxidant (2% hydrogen peroxide for 1 hour), with or without heat, also did not appear to affect the color.

On March 24, 1997, algae samples were submitted by the KDHE Southcentral District Office from a stream near Sharon, Kansas. Complaints had been phoned into the district office concerning the possible discharge of a dairy farm's slurry tank into the creek. Samples collected upstream of the potential discharge contained an abundance of filamentous green algae (<u>Spirogyra</u> spp.) and a fairly large community of diatoms. Samples collected downstream of the potential discharge contained an abundance of filamentous blue-green algae (<u>Oscillatoria</u> spp.), a small amount of <u>Spirogyra</u> spp., and an even larger diatom community (up to 4 times more abundant) than what was found upstream. While the algae community did show an abrupt change in species composition and biomass, the identification of a pollution event was confounded by the presence of springs and seeps along the stream. Total phosphorus concentrations were fairly high, both upstream and downstream of the dairy operation, although slightly higher concentrations were noted downstream. If a slurry tank discharge had caused the changes in the resident algae community, it would likely need to have occurred more than once and would likely be flushed fairly quickly due to the inputs from the springs.

On July 19, 1997, staff from the KDHE Southcentral District Office collected algae samples from the Little Arkansas River in western Harvey County. The complaint had been originally reported to Harvey County Emergency Management as a possible oil spill. KDHE staff found that the water had a surface covering of slime, a large amount of organic debris, but no odors or oil sheens. The algae community was composed of roughly 20,000 cells/mL of a dinoflagellate (Gymnodinium sp.) and a blue-green algae (Aphanizomenon flos-aqua). Under stagnant conditions, large algae communities such as this can produce surface sheens of oily substances.

On July 23, 1997, KDHE Southcentral District Office staff again collected algae samples from the Little Arkansas River below the dam at Harvey County West Park. This time complaints had been phoned in concerning foam below the dam. The algae community was composed of about 7,000 cells/mL of the blue-green algae Aphanizomenon flos-aqua, which would be typical of this small lake during summer months. District Office staff were informed that the conditions described at this lake (organic debris, low flow, and hot temperatures) often produced some foaming below the discharge. The difference between this type of foam, and that produced by detergents, etc., is that this foam tends to dissipate somewhat faster. District Office staff reported that this was the case, with foam dissipating a short distance downstream.

On July 24, 1997, staff from the KDHE Southeast District Office collected algae samples along the Spring River, in Cherokee County, in response to several episodes of septic odors along the river. Algae samples suggested that the community in the river was typical of a shallow river impoundment (Empire Lake impounds the Spring River along the area in question). However, cell counts and biomass estimates did not appear high enough to have caused the odor incidents, despite the fact that some of the algae groups identified are known to cause septic odors in waterbodies.

On August 1, 1997, a citizen called the KDHE Central Office concerning a pond near Overbrook, Kansas, where several sheep had died within 24 hours of drinking at the pond. KDHE Northeast District Office staff indicated that the normal response for livestock kills was to refer pond owners to their veterinarian. However, as there was a potential for the livestock kills to be the result of toxic algae, it was agreed that KDHE staff in Topeka would make the brief trip to Overbrook, Kansas. Mats of filamentous green algae and surface scums of Euglena sp.

constituted the community within this very small and shallow pond, with no indication of any abundant algae that are known to produce toxins. The pond owners were encouraged to contact their veterinarian so that a cause for the deaths could be identified.

On August 8, 1997, KDHE Southcentral District Office staff submitted algae samples from a fishkill at Winfield Park Lagoon, a "doughnut" shaped lake used as a city park (believed to be a modified oxbow lake). Examination of the algae samples revealed a very large community of blue-green algae. The most common form was the filamentous <u>Phormidium</u> sp., but <u>Anabaena</u> spp. were also very abundant. Although these algae forms are documented as able to produce toxins, it was indicated that night-time dissolved oxygen depletion was the most likely cause of the fishkill. This conclusion was arrived at because of the recent warm temperature, closed nature of the pond's hydrology, and the fact that only gizzard shad (<u>Dorosoma cepedianum</u>) were killed.

On September 3, 1997, KDHE Southcentral District Office staff once again were called to the Little Arkansas River, near the Harvey County West Park, due to complaints about foam in the river. All locations sampled had moderate-to-high phytoplankton communities composed primarily of blue-green and green algae. The most abundant algal species was the blue-green <u>Aphanizomenon flos-aqua</u>. As before, these samples also contained an abundance of organic matter which would likely promote foaming if the water were agitated, such as would be the case below a dam outfall or a stream riffle.

On September 12, 1997, KDHE Southcentral District Office staff collected samples in response to a citizen complaint about horses suddenly refusing to drink from Salt Creek, west of Hutchinson, Kansas. Algae samples, collected as part of the investigation, contained abundant communities composed primarily of diatom and dinoflagellate algae. Samples were also noted to be full of both organic and inorganic debris. While it was indicated that the algae community could be producing some substance that was not palatable to the horses, it could also be a combination of organic/inorganic material, algal byproducts, and stream salinity (the name "Salt Creek" suggests that normal salinity levels are somewhat high). Mean chloride concentration in Salt Creek is about 1,350 mg/L.

CONCLUSIONS

The following conclusions are offered, based upon the lake monitoring data obtained during 1997.

1. Trophic state conditions suggested that most lakes surveyed in 1997 were stable (about 36%) or degrading (about 33%), in terms of past trophic state compared to current condition. Of

the remaining lakes, 24% displayed some improvement in trophic status compared to their last survey. This is reasonably consistent with past years of survey data.

2. Exceedences of surface water quality criteria and guidelines revolved primarily around three parameter groups. These included eutrophication and high nutrient loads, pesticide levels (primarily atrazine), and in-lake processes (high pH due to algal productivity and low dissolved oxygen due to shallow thermoclines). It is likely that the low dissolved oxygen problems can be primarily attributed to natural processes or background conditions, or secondarily, to other water quality problems (i.e., eroded soil or high trophic state). Eutrophication problems are primarily due to excessive nutrient loads. Pesticide problems relate almost entirely to agricultural practices and tend to be seen more frequently in the lakes of northeast and east central Kansas.

3. Twenty-one of the 33 surveyed lakes (64% of the total) had detectable concentrations of agricultural pesticides during the summer of 1997. Atrazine was the most commonly encountered pesticide (58% of lakes). Five of these lakes met, or exceeded, the drinking water supply criterion for atrazine (15% of lakes). While no criteria exist (or were not exceeded where they did exist) for metolachlor (Dual), alachlor, or deethylatrazine, detections of these three pesticides were frequent and of concern to water quality.

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LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620-0001. All data referenced within this report are also accessible on the EPA STORET electronic database.

Appendix A

Macrophyte Communities

In 88 Lake and Wetland Program

Waterbodies

The term "macrophyte" is commonly used to describe all vascular aquatic plants (both obligate and facultative hydrophytes) that live in, or near, lakes, streams, and wetlands, including forms of macroscopic algae. For the purposes of this report and Program, macrophytes are those larger aquatic plants that include submersed and floating-leaved vascular plants, and the macro-algae commonly called "stoneworts." Macrophytes, depending on individual lake conditions, can contribute significantly to primary productivity, food web stability, community composition for fish and invertebrates, and overall ecological integrity. When extremely abundant, they can also have adverse impacts on the functioning of lakes and ponds.

In 1990, staff of the KDHE Lake and Wetland Monitoring Program began to collect semi-quantitative data about the macrophyte communities in network lakes that were smaller than 300 acres in surface area (KDHE, 1995). In lakes much larger than 300 acres, the availability of suitable shoreline habitat tends to preclude extensive rooted macrophyte communities, making such surveys somewhat unproductive. For the largest lakes in Kansas (>800 acres), annual water level manipulations virtually eliminate the potential for macrophyte community development. However, a few lakes larger than 300 acres have been surveyed for macrophytes as part of special sampling projects.

Now that the great majority of the network lakes, which met the sampling criteria, have received at least one plant survey, a review of the data for geographic and water quality trends is appropriate. Such an analysis will be used, in part, to determine future macrophyte sampling needs for network lakes.

Statewide Macrophyte Cover

The literature contains many references to the ecological roles of macrophyte communities in lakes and reservoirs. For example, macrophytes tend to restrict water movement and trap silt, provide shade within the water column, retard heat transfer within the water column, alter water chemistry (dissolved oxygen, alkalinity, pH, hardness, nutrients) on seasonal and diel scales, provide habitat for invertebrates and fish, enrich plankton diversity, support waterfowl, and form feedback loops within trophic layers of the lake ecosystem which, in turn, supports ecosystem stability.

Because of these many roles macrophyte communities are an important component in both lakes and reservoirs, although there are reasons to believe that macrophytes are, generally, a less important ecological component in reservoirs than in natural lakes (Doyle & Smart, 1997). Among the reasons for this belief are 1) the fact that reservoirs tend to be deeper than comparably sized natural lakes, 2) water level fluctuations in reservoirs may prevent rapid establishment of aquatic plants along the littoral zone, and 3) transport of water, nutrients, and other materials tends to be faster in reservoirs.

The literature also contains many references to the "optimal" amount of plant cover for fishery maintenance (primarily largemouth bass/bluegill fisheries). Most researchers tend to feel that optimal largemouth bass fisheries occur when plant cover is 10-to-40%, with 30% often cited as a goal for lake management (Maceina, 1997). For the purposes of this report, the 30% macrophyte cover is viewed as "optimal" for most uses, including fisheries maintenance, while plant covers above 60% are viewed as detrimental to most uses, including fisheries.

Statewide, about half of the lake surveys have shown detectable amounts of plant cover, using the method employed by KDHE staff (KDHE, 1995). Table A1 describes statewide macrophyte cover. For the entire population, 49% of lake surveys had some detectable level of plant community, while 36% had what might be considered "optimal" levels. Only 20% had what would be considered excessive macrophyte cover. Among the population of lakes surveyed, the average amount of plant cover was 26%. Given that the median value is zero, it follows that a considerable number of lakes did not have detectable macrophyte communities. A lack of macrophyte communities may result from lake water quality (high chronic turbidity), competition with phytoplankton, lake morphometric and hydrologic conditions, or the presence of grass carp (*Ctenopharyngodon idella*).

Regional Trends in Cover

Macrophyte cover was also examined among the six major EPA ecoregions located within Kansas. Table A2 shows the basic descriptive statistics for the six ecoregions, while Table A3 provides data on the number of lakes that exceed different levels of plant cover. Figure A1 provides evidence of an east-west trend in the prevalence of macrophyte cover in Kansas lakes. There has long been a belief among fisheries biologists (personal conversations) that western Kansas lakes have a higher potential for macrophyte colonization. Figure A1 combines lakes into successive groups that describe "slices" of the state in a west-east manner. In this way, a west-to-east trend is shown, but one must remain cognizant that there are local small regions that vary greatly (such as ecoregion 47 versus 40). One must also remember that, while lake network sites are selected to present as representative a sample of physical conditions for each region as possible, logistical needs must also be met. No feasible monitoring network can be truly random.

Table A1. Statewide macrophyte cover conditions within the population of lakes surveyed.

	Total Cover	No. >0% Cover	No. >30% Cover	No. >60% Cover
Minimum	0%	-	-	-
25th Percentile	0%	-	-	-
Median	0%	-	-	-
75th Percentile	50%	-	-	-
Maximum	100%	-	-	-
Number of Surveys	93	43	32	18
Mean	26%	49%	36%	20%

Table A2. Macrophyte cover for the six major EPA ecoregions within the state. Due to a small sample size in ecoregion 25 and 26, these lakes were combined for calculations. Names for the ecoregion numbers follow the table, with the corresponding Kansas physiographic regions identified.

	Ecoregion				
	25&26	27	28	40	47
Minimum	0%	0%	0%	0%	0%
25th Percentile	0%	0%	0%	0%	0%
Median	60%	0%	0%	0%	35%
75th Percentile	100%	70%	8%	34%	80%
Maximum	100%	100%	80%	100%	90%
Mean	43%	37%	13%	20%	41%

Ecoregion 25 = Western High Plains (High Plains)
Ecoregion 26 = Southwestern Tablelands (Red Hills)
Ecoregion 27 = Central Great Plains (Smoky Hills/Ark River Lowlands)
Ecoregion 28 = Flint Hills (Flint Hills)
Ecoregion 40 = Central Irregular Plains (Osage Cuestas)
Ecoregion 47 = Western Cornbelt Plains (Glaciated Region)

Figure A1. Mean macrophyte cover, statewide and for individual ecoregions. Ecoregions have been combined to allow a better examination of progressive west-to-east geographical portions of the state.

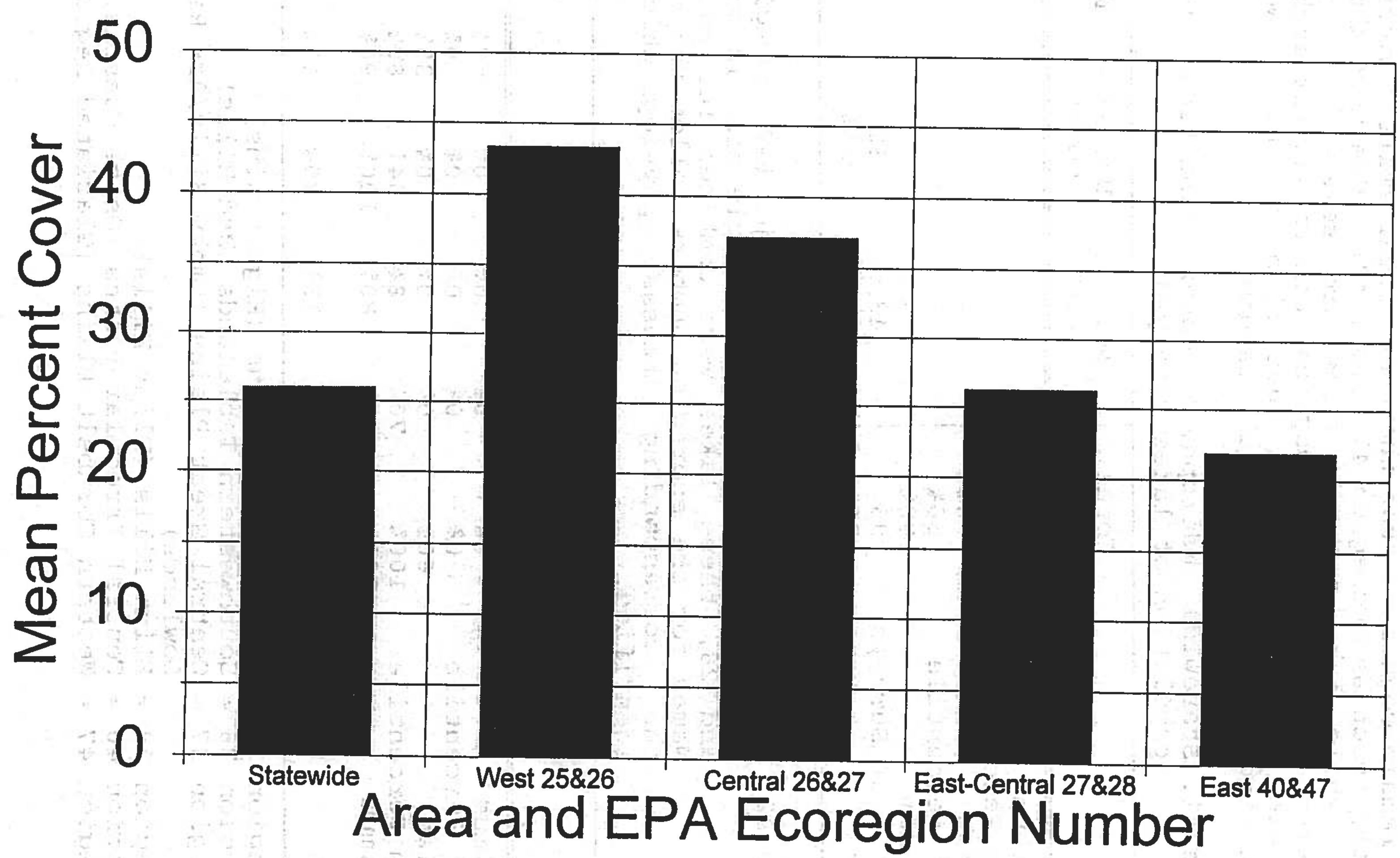


Table A3. Number of lakes exceeding different levels of macrophyte cover among the different EPA ecoregions. See the list associated with Table A2 for the ecoregion names and corresponding physiographic regions.

Ecoregion Number	Number Of Lakes In Region	Percent of Lakes Exceeding 0%	30%	60%
25	5	60%	60%	60%
26	3	33%	33%	0%
27	19	47%	47%	32%
28	15	40%	20%	7%
40	41	44%	27%	12%
47	5	60%	60%	40%

From an examination of the data in Tables A2 and A3, it appears that macrophyte cover is greatest in lakes located in the western third of the state or in the northeast corner. In both locations, a greater prevalence of shallow waterbodies might help explain the higher cover values, although other factors certainly also exert influence. For the Flint Hills (28) and the Central Irregular Plains (40), far fewer lakes appear to have excessive macrophyte communities. In the Western High Plains (25), Central Great Plains (27), and the Western Cornbelt Plains (47) a larger proportion of those lakes with macrophyte communities have levels that might be termed excessive.

Although difficult to see from individual ecoregional data, combining data to describe "blocks" of the state, moving west-to-east, allows a trend to be observed (Figure A1). Despite localized regions of high or low macrophyte abundance, Figure A1 does indicate a trend of decreasing macrophyte cover as one progresses eastward through the state. This is likely a combination of regional lake size and depth, regional hydrology, and regional climatic conditions.

<u>Trends Based on Lake Condition</u>

Many physical and water quality based characteristics of lakes may have an influence on the development of a macrophyte community. While data for many physical aspects of lakes are lacking, surface area and maximum/mean depth data was readily available to compare with macrophyte cover estimates. Likewise, a comparison of macrophyte cover with water quality variables could be a very time intensive prospect given the number of water quality variables examined during lake sampling. Chosen as a general indicator of lake water quality, trophic state was compared to macrophyte cover. Specifically, macrophyte cover was compared to the Carlson chlorophyll-a TSI score.

Figure A2. Graphical comparison of lake surface areas and percent macrophyte cover, with best fit line for the data.

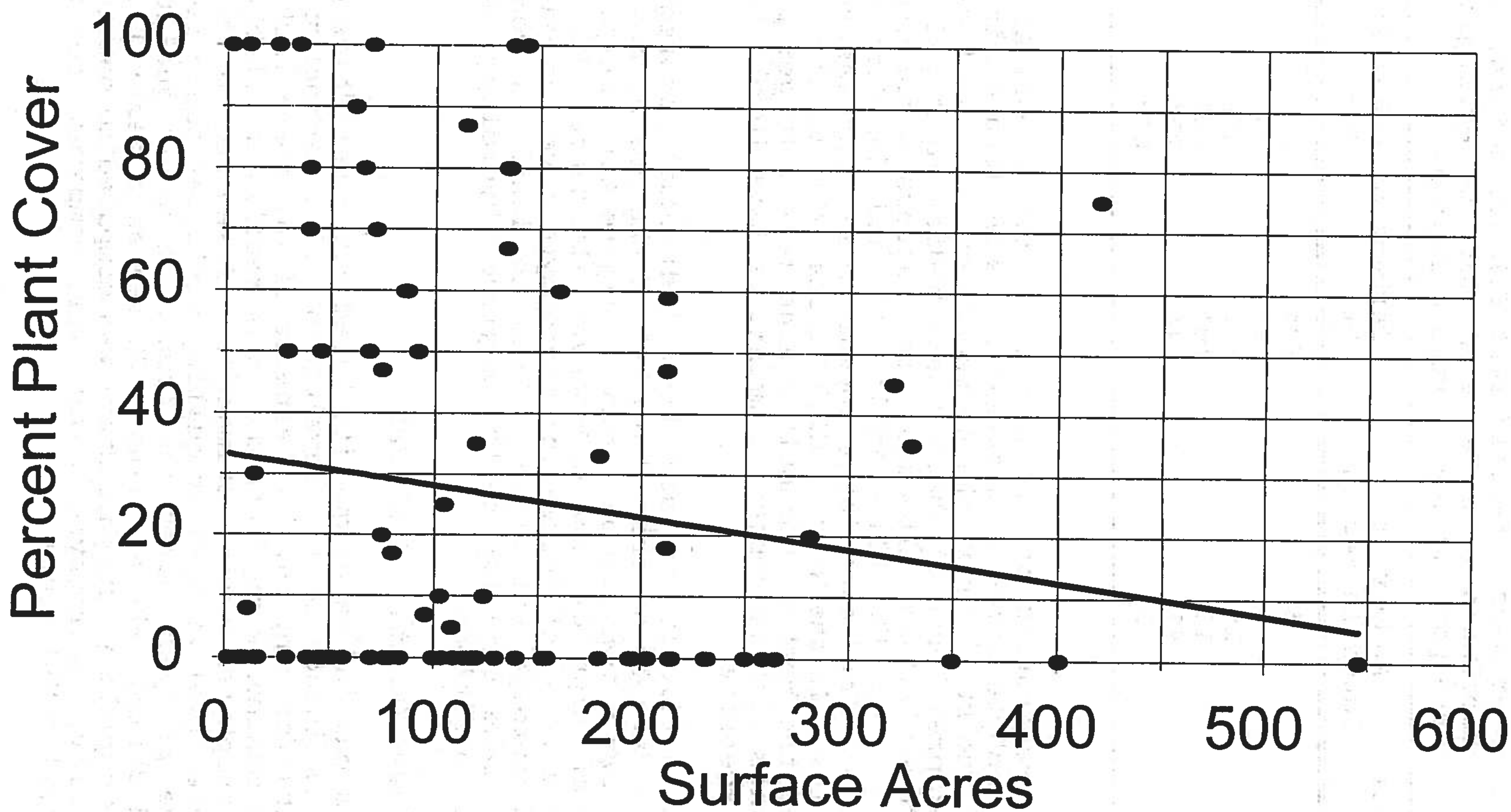


Figure A3. Graphical comparison of maximum lake depth and percent macrophyte cover, with best fit line for the data.

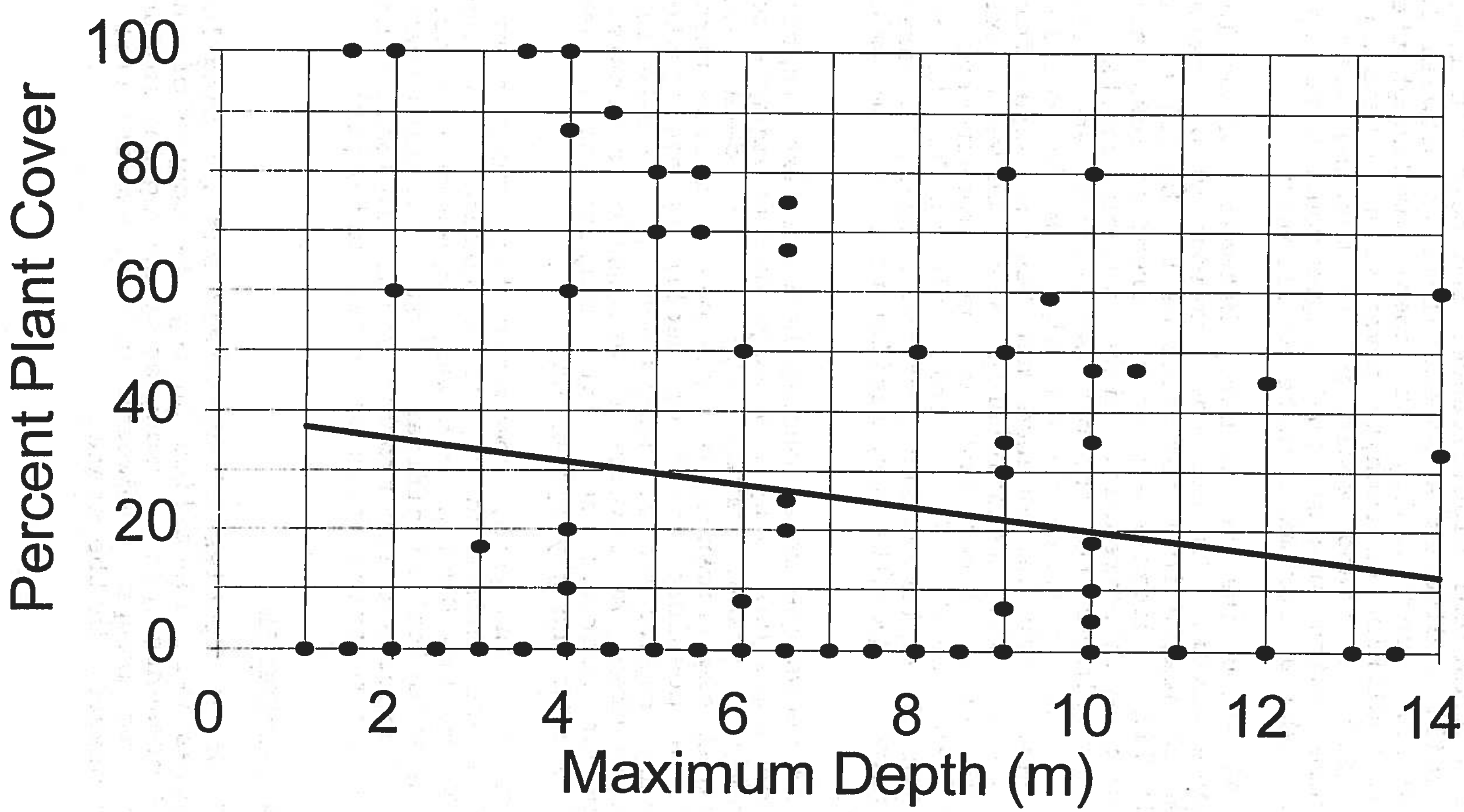


Figure A2 shows the relationship between lake surface area and macrophyte cover. While the variability of the data result in a lack of statistical significance, the best fit line through the points still indicates a potential trend between lake size and plant cover. Specifically, it appears as though there is a weak trend of declining macrophyte cover with increasing lake surface area. Such a trend would be in keeping with data in the literature, which suggests that larger constructed lakes have less suitable habitat for macrophyte development.

Figure A3 shows the relationship between maximum lake depth and macrophyte cover. As for the previous graph, data variability produces no statistical significance to the relationship, but the best fit line indicates a possible trend of less macrophyte cover as maximum depth increases. Higher maximum depths, in a number of cases, translates to steeper shorelines and less macrophyte habitat. An inverse relationship is in keeping with such conditions. Mean depths have not been measured for many Kansas lakes, but a strong relationship exists between maximum and mean depth for those lakes that do have measurements ($R^2 = 0.98$, $P<0.001$, 35 lakes). Using this relationship to calculate mean depths for these lakes, and plotting mean depth versus macrophyte cover, provides results very similar to those when maximum depth is used.

Figure A4 shows the relationship between lake trophic state index (based on algal chlorophyll-a only) and macrophyte cover. As for the previous graph, variability in the data resulted in no statistical significance, but the best fit line through the data suggests a possible trend of declining macrophyte cover with increasing trophic state. This trend too would be in keeping with the literature. An inverse relationship is consistent with the paradigm of nutrient and light competition between submersed aquatic plants and phytoplankton.

An additional analysis, comparing lake surface area with lake trophic state indicated no relationship. The best fit line described by the data points was, in essence, a horizontal line with no statistical significance. This suggests that lake size is much less important for trophic state development than are other morphometric features (such as volume and depth).

Individual Species

A total of 20 species of submersed and floating-leaved aquatic macrophytes were identified during the course of these surveys. Table A4 presents species richness by ecoregion, including richness data for two groups (pondweeds and stoneworts) that had multiple species present in the state.

Figure A4. Graphical comparison of lake trophic state score, based on algal chlorophyll-a, versus percent macrophyte cover.

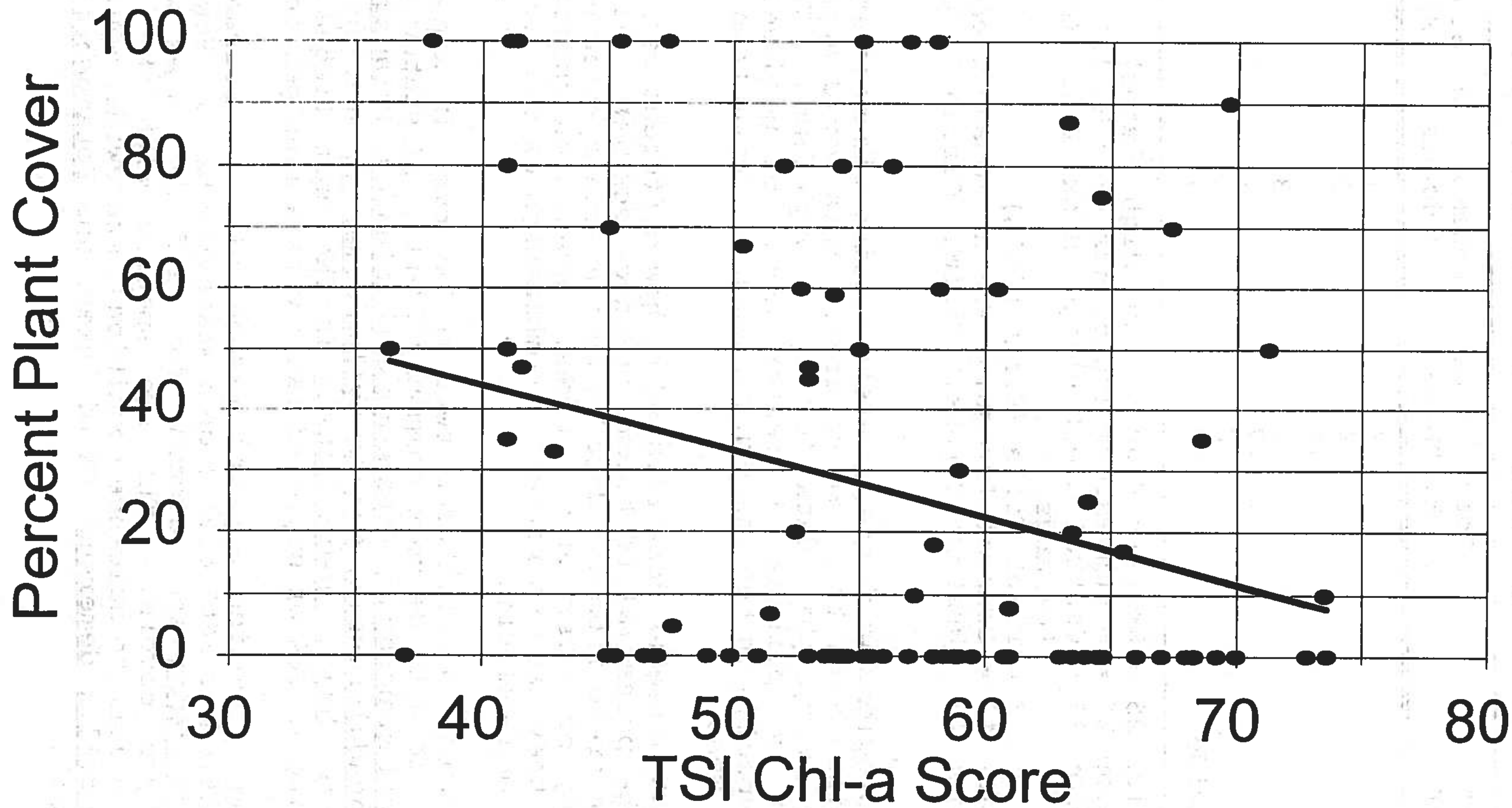


Table A4. Macrophyte species richness by EPA ecoregion and statewide, expressed as number of species identified.

Region Number	Total Species Richness	Potamogeton Richness	Stonewort Richness
25	5	1	2
26	4	2	1
27	10	4	1
28	7	3	2
40	17	7	4
47	6	4	0
Statewide	20	7	6

Ecoregion 25 = Western High Plains (High Plains)
Ecoregion 26 = Southwestern Tablelands (Red Hills)
Ecoregion 27 = Central Great Plains (Smoky Hills/Ark River Lowlands)
Ecoregion 28 = Flint Hills (Flint Hills)
Ecoregion 40 = Central Irregular Plains (Osage Cuestas)
Ecoregion 47 = Western Cornbelt Plains (Glaciated Region)

The ecoregions with the greatest species richness are also the two ecoregions with the largest area. This would appear consistent with biogeographic data for other organisms. The only trend evident is, perhaps, a greater number of pondweed (Potamogeton spp.) species in the eastern portions of Kansas than would be found in the west.

Table A5 presents data related to how different macrophyte species have the potential to become nuisance species. Perhaps the most evident trend from the data is that no one species contributes the majority of cover in our lakes. Even when nuisance conditions exist, they tend to reflect a combination of species rather than a strict monoculture.

Even though monocultures tend to be rare in Kansas lakes, six species tend to be more commonly identified statewide. These are Potamogeton nodosus, Potamogeton pectinatus, Potamogeton foliosus, Najas guadalupensis, Ceratophyllum demersum, and Chara globularis. Of these, Najas guadalupensis is the most frequently detected, appearing in 26% of surveyed lakes with a mean percent cover of 7%.

No single species appears responsible for nuisance conditions (identified as >60% cover) on a statewide basis. However, mixtures of Potamogeton spp. account for half the lakes with excessive macrophyte covers. The two species with the greatest solo contributions to nuisance conditions, statewide, would appear to be Ceratophyllum demersum (6% of lakes) and Potamogeton foliosus (5% of lakes).

Table A5. Exceedence of different levels of cover for individual species statewide and mean percent cover for each species.

Species	Mean Cover	Percent Surveys Exceeding >0% Cover	>30% Cover	>60% Cover
Potamogeton spp.	13%	33%	20%	10%
P. nodosus	5%	18%	7%	2%
P. pectinatus	6%	16%	9%	2%
P. foliosus	5%	11%	9%	5%
P. pusillus	2%	7%	3%	0%
P. crispus	1%	2%	1%	0%
P. illinoensis	1%	1%	1%	1%
P. diversifolius	<1%	1%	0%	0%
Chara & Nitella spp.	8%	23%	10%	3%
C. globularis	4%	11%	7%	1%
C. zeylanica	1%	8%	1%	0%
C. vulgaris	1%	1%	1%	1%
C. canescens	1%	1%	1%	1%
C. braunii	<1%	1%	0%	0%
N. flexilis	1%	5%	1%	0%
Najas guadalupensis	7%	26%	10%	2%
Ceratophyllum demersum	8%	15%	9%	6%
Myriophyllum spp.	5%	8%	7%	3%
Nelumbo spp.	1%	5%	2%	1%
Lemna spp.	1%	1%	1%	1%
Nymphaea spp.	<1%	1%	0%	0%
Zanichellia palustris	<1%	1%	0%	0%
All Species	26%	49%	36%	20%

Individual regions of the state indicate different levels of macrophyte growth, however. It would, therefore, stand to reason that these regions may be influenced more by certain individual macrophyte species. Examining each of the six EPA ecoregions yields the following information.

In the Western High Plains (ecoregion 25), the most common macrophyte species include <u>Ceratophyllum demersum</u>, <u>Myriophyllum</u> spp., <u>Chara vulgaris</u>, and <u>Chara canescens</u>. While pondweeds are present, they do not represent an important component for macrophyte communities in this region. Although all four species contribute equally to nuisance conditions, mixed communities still tend to be present but usually dominated by one species. In the Western High Plains, 60% of surveyed lakes have nuisance levels of macrophyte cover. However, only five lakes in this far western region of the state have been surveyed.

In the Southwestern Tablelands (ecoregion 26), the most common species include Potamogeton nodosus, Potamogeton pectinatus, Myriophyllum spp., and Chara globularis. None of the three lakes surveyed in this smaller ecoregion have had nuisance macrophyte conditions.

In the Central Great Plains (ecoregion 27), the most common species include Potamogeton nodosus, Potamogeton pectinatus, Myriophyllum spp., Najas guadalupensis, and Chara globularis. In this central region of Kansas, 32% of surveyed lakes had nuisance macrophyte conditions. The species most responsible for these conditions include Potamogeton pectinatus and Najas guadalupensis mixtures. A total of 19 lakes have been surveyed in this ecoregion.

In the Flint Hills (ecoregion 28), the most common species include Potamogeton nodosus, Potamogeton foliosus, Najas guadalupensis, Chara globularis, and Nitella flexilis. Only 7% of the 15 lakes surveyed in this region had nuisance levels of macrophytes (1 lake) and the species of concern was Potamogeton foliosus.

In the Central Irregular Plains (ecoregion 40), the most common species include Potamogeton nodosus, Potamogeton foliosus, Potamogeton pusillus, Potamogeton pectinatus, Najas guadalupensis, Chara globularis, and Chara zeylanica. However, only 12% of the 41 surveyed lakes within this region had nuisance conditions. In these cases, mixed communities of pondweeds were the cause.

In the Western Cornbelt Plains (ecoregion 47), the most common species included Potamogeton nodosus, Potamogeton foliosus, Potamogeton pusillus, Potamogeton pectinatus, Ceratophyllum demersum, and Najas guadalupensis. Fully 40% (2 out of 5) of the surveyed lakes in this smaller ecoregion had nuisance levels of macrophytes. Species of concern were Ceratophyllum demersum and Potamogeton foliosus.

Several trends in species across Kansas are discernable from these data. First, pondweeds appear much more common as one progresses eastward across Kansas. The contributions of pondweeds towards nuisance conditions appears greatest in the northeast corner of the state. The individual species Potamogeton foliosus and Potamogeton pusillus appear more common in the eastern part of Kansas. Second, Ceratophyllum demersum appears common throughout the state but more of a potential nuisance in either far western or northeast Kansas. Third, Myriophyllum spp. are far more common in western Kansas. Fourth, Najas guadalupensis appears to be absent in most western Kansas waterbodies, but becomes more common as one progresses east across the state. However, it rarely appears at nuisance levels. Fifth, stoneworts (Chara and Nitella spp.) are common across the state, but only achieve nuisance conditions in far western Kansas. Individual stonewort species appear to be more, or less, common in different regions. Chara vulgaris and Chara canescens appear more common in western Kansas while Chara globularis, Chara zeylanica, and _Nitella flexilis_ appear more common in the eastern half of the state.

Conclusions and Recommendations

All the data presented in this Appendix suggest that over-abundance of macrophytes is not a common problem in Kansas lakes. Far more common is the total lack of macrophytic habitat (51% of surveyed lakes), along with all the reduced benefits that can bring. Most of those lakes with high cover estimates tended to have mixtures of species, although it was often the case that one-or-two species dominated the biomass present. On the other hand, 36% of the lakes surveyed had levels of plant cover that might be considered optimal. Nearly half of the lakes surveyed did have some level of macrophyte community present. These lakes should be managed to protect this macrophyte habitat and maintain cover at current levels.

It is further suggested that macrophyte control, or eradication, should not be perceived as a widespread need. Too often, macrophyte growth is viewed as a detriment to lake uses, especially to fishing, without any regard to the potential problems associated with elimination of macrophyte communities. Problems resulting from macrophyte growth appear to be highly related to specific conditions at individual lakes. Therefore, macrophyte control should be targeted at only those lakes where 1) plant cover and biomass are high and 2) the macrophyte growth can be shown to cause a serious loss of beneficial use.

As a last note, any person (fishery biologist, concerned citizen, ecologist, or lake manager) desiring to use this data to justify a particular position should be aware of the following. The technique used (presence/absence at a number of locations across the lake) is a compromise between desiring data on macrophyte communities in Kansas lakes and minimizing the staff time required to collect data. Cover estimates derived from this technique may not be directly related to 1) plant biomass, 2) the volume of the lake filled with macrophyte beds (i.e., percent volume infested), or 3) plant density within beds. All of these aspects of macrophyte communities would play a role in making any management decision for a specific lake. It is recommended that any manager(s) responsible for making such decisions collect data on these additional aspects of the plant community, and objectively analyze such data, before embarking on a macrophyte control plan for a given lake.

Appendix B

Hillsdale Lake Estimated Pollutant Loads
Modified Based on United States Geological Survey
Sediment Core Study Data
And
1997 Water Quality Data

Hillsdale Lake, located in northeastern Miami County, Kansas, has been the subject of attention since the mid-1980's when the lake first filled. Given the relatively small watershed-to-lake area relationship, the number of existing point sources, the relative "newness" of the lake, and the location near a rapidly expanding urban area, concerns about nutrient pollution and eutrophication have come to the forefront. A number of studies have been conducted over the years in an attempt to estimate the amount of phosphorus entering the lake from a variety of watershed sources. Phosphorus has been clearly identified as the primary factor limiting algal production in Hillsdale Lake. The most recent study used sediment core data to calculate the historic phosphorus load to Hillsdale Lake (USGS, 1997), requiring that KDHE modify its earlier report on nutrient loading to Hillsdale Lake (KDHE, 1994).

Previous studies, specifically the work done by KDHE, indicated that a total phosphorus load of 18,000-to-20,000 kg/yr needed to be present to produce the in-lake water quality that has been observed. Two independently developed models (EUTROMOD and CNET/BATHTUB), using versions based on Midwest reservoirs, provided similar annual average load estimates, based on observed water quality conditions. Both models were applied under the assumption that "total" phosphorus was the fraction that controlled the production of algal biomass. This view is consistent with the majority of limnological literature (Wetzel, 1983; EPA, 1990; Correll, 1998).

In 1993, a Section 319 Nonpoint Source Pollution grant was awarded for what is now known as the Hillsdale Lake Water Quality Project. Part of this grant was used to begin stream monitoring in order to attempt a more direct calculation of phosphorus loads to the lake. However, total phosphorus data from these streams appeared to indicate that annual loads might average somewhere in the 50,000-to-90,000 kg/yr range. Given that the four years sampled under this project were all above normal precipitation years, or years with an abnormal number of intense storm events, the data was viewed by KDHE staff as potentially unrepresentative for calculating annual mean loads.

The recently released USGS study (USGS, 1997) attempted to use a different means to estimate phosphorus loads to Hillsdale Lake by collecting sediment cores from material that had been accumulated since the lake filled. These data indicated that annual mean phosphorus load was in the range of 65,000-to-70,000 kg/yr. This data was more in line with observed stream concentrations, but suggested that in-lake total phosphorus should be much higher than had ever been observed. Since in-lake nutrient levels were nowhere near those expected under a loading of 60,000-to-70,000 kgP/yr, the most likely conclusion was that a large portion of the phosphorus entering the lake found its way, rapidly, into the sediments and was not available for algae production. Therefore, the use of an "available" phosphorus model should be able to predict algal growth in Hillsdale Lake and provide a new set of loading numbers for eutrophication management.

Availability Model Using CNET

The CNET/BATHTUB model contains such an "available phosphorus" model. This had been examined early on by KDHE staff but shelved as it suggested total phosphorus loads much higher than observed in any study of Hillsdale Lake. Because evidence stemming from the recent USGS study (USGS, 1997) indicated such high total phosphorus loads were indeed occurring, use of the availability model was reconsidered by KDHE.

Table B1 presents the loading estimates from this model, based on water quality data through 1997 (less suspect 1996 chlorophyll-a data), and hydrological data through 1996. These estimates should reflect observed lake conditions over the long-term. Long-term mean water quality is calculated by averaging individual, yearly, summer-time (early June-to-early September) mean values for each station. Whole-lake means are then calculated by averaging the three lake stations. This sequence is imperative because each year, and station, has had a different amount of sampling effort applied by the various agencies. Averaging of these separate yearly means tends to eliminate any bias towards those years or locations with the greatest sampling effort. In the case of 319 Project data, greatest sampling effort took place during above normal rainfall years.

The period extending from early June to early September is the appropriate time frame to utilize, given that 1) both the CNET and EUTROMOD water quality models express water quality results as summer-time values, and 2) the greatest user interaction with the lake will occur from Memorial Day to Labor Day. While water supply withdrawals occur all year, this use should be somewhat greater during the warmer months.

Phosphorus availability factors used in the model were 0.8 for point sources, 0.23 for nonpoint sources, and 0.5 for atmospheric sources. The value for point sources should be considered a minimum value: 90% or more of the phosphorus contributions from point sources may be readily available for algal uptake (Reckhow, 1980, 1990). The value for nonpoint sources is based largely on water quality data collected at the largest nonpoint source impacted stream in the Hillsdale Lake watershed (Rock Creek).

Only data collected from early June to early September were used because it is the period when Hillsdale Lake begins to warm and stratify, signalling the onset of "summer" growing season for the algae. Breakdown of stratification, and lake turnover, typically occurs in Hillsdale Lake by mid-to-late September. Also, much of the rainfall in northeast Kansas comes during spring runoff events (prior to June). These events tend to place Hillsdale Lake in temporary disequilibrium as regards surface water quality. At such times, lake surface waters are more turbid and are flushed more rapidly than would be true for the year as a whole. There exists, therefore, a good reason for avoiding the use of springtime, and post-storm collected, water quality data in calculating mean lake water quality.

Table B1. Revised phosphorus loads for Hillsdale Lake, in light of recent USGS data and using the CNET available phosphorus model. These water quality values and load estimates represent the long-term mean values for this system.

Parameter	Mean Annual Load		
Phosphorus Loading			
Total P-Load			
Atmospheric	853	kg/yr	1%
Point Sources	5,050	kg/yr	8%
Nonpoint Sources	59,115	kg/yr	91%
Total	65,018	kg/yr	100%
Available P-Load			
Atmospheric	426	kg/yr	2%
Point Sources	4,040	kg/yr	23%
Nonpoint Sources	13,596	kg/yr	75%
Total	18,063	kg/yr	100%
Parameter		**Units**	
Summer Water Quality (Whole-Lake 1986-1997)			
Mean In-Lake TP	54.01	ug/L	
Mean Chlorophyll-a	14.53	ug/L	
Mean Secchi Depth	0.99	meters	
Non-Algal Turbidity	0.64	1/meter	
Walker TN/TP Ratio	17.8	---	
Chlorophyll/TP Yield	0.27	---	
Nuisance Algae Frequency	60.7	% of summer	

Some midwestern lakes also tend to experience surface overflows during large runoff events, while others experience the runoff as subsurface underflows (Jones, 1997). The lakes that experience these runoff "slugs" as overflows tend to undergo temporary periods of water quality disequilibrium. Incorporating data from such times, into the data from the remainder of a year, may not provide a valid analysis of "average" conditions. During such periods of disequilibrium light may become more important in limiting phytoplankton growth, although the importance will be temporary. The temporary increase in flushing rate may, likewise, limit phytoplankton production and may be of more importance than temporary increases in turbidity.

Regarding some of the data from Table B1, available phosphorus load constitutes about 28% of the total load. "Available" phosphorus load includes any form that can be immediately taken up by algae (all dissolved forms), plus any other (e.g., particulate) form that has a potential for transformation into forms that can be readily assimilated. This suggests that over 70% of what enters Hillsdale Lake is refractory in nature and settles fairly quickly to the sediments. The CNET/BATHTUB model calculates that about 73% of the phosphorus entering the lake will be retained, under current conditions.

Non-algal turbidity (Walker, 1986) is calculated, for the period of record, at 0.64 m^{-1}. Values less than 0.4 indicate very clear waters with little inorganic suspended materials. Values above 1.0 indicate that inorganic suspended materials are becoming significant and light limitation of algae is becoming more possible. At 0.64 units, Hillsdale Lake is not considered to be light limited, but there are times and locations where light plays a small role (spring runoff, post-storm times in summer and fall, etc.). The chlorophyll/TP yield (Walker, 1986) is about 0.27 for the period of record. Lakes and reservoirs with values below 0.13 are indicated as being systems where algal production is not very strongly linked to phosphorus. Values above 0.4 indicate systems with a very strong link between algal production and total phosphorus. At half-way between the transition values, Hillsdale Lake is indicated as having a "moderate" algal response to changes in phosphorus levels over the last 15 years.

Given recent suggestions that light limitation may be important for Hillsdale Lake, some examination of the data is appropriate. Figures B1, B2, and B3 provide an analysis of all paired Secchi depth/chlorophyll-a data for Hillsdale Lake (256 pairs of data points). Figure B1 examines the relationship between Secchi depth (classic estimator of water transparency) and the non-algal (inorganic) turbidity metric. It is well accepted that Secchi depth readings are far more linked to non-algal turbidity than to algal-induced turbidity (Davies-Colley, et. al., 1993; Wetzel,

Figure B1. Secchi depth versus non-algal turbidity, in Hillsdale Lake, for the period of record (256 data pairs). The best fit line is also indicated.

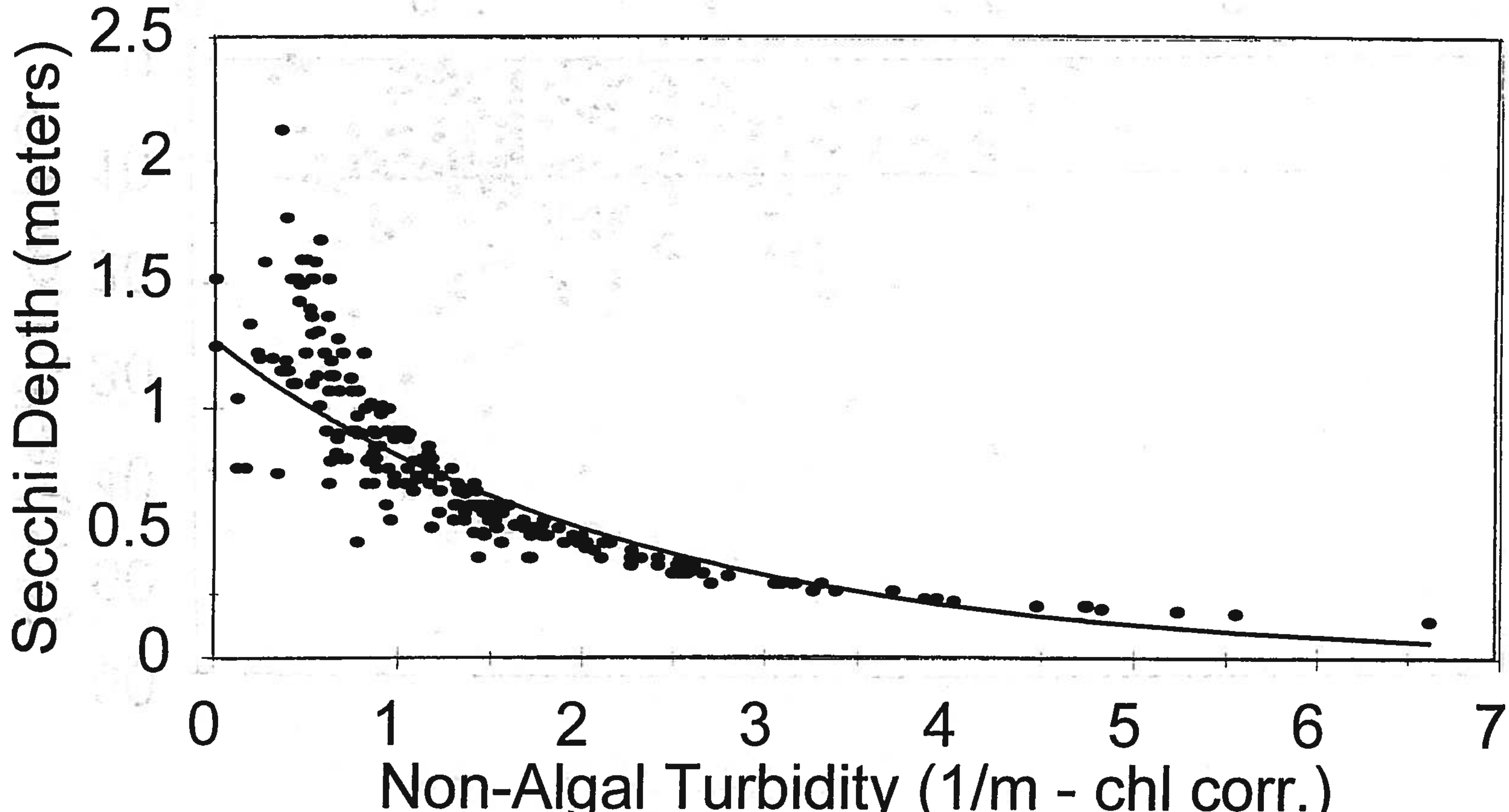


Figure B2. Algal chlorophyll-a versus Secchi depth, in Hillsdale Lake, for the period of record (256 data pairs). The best fit line is also included.

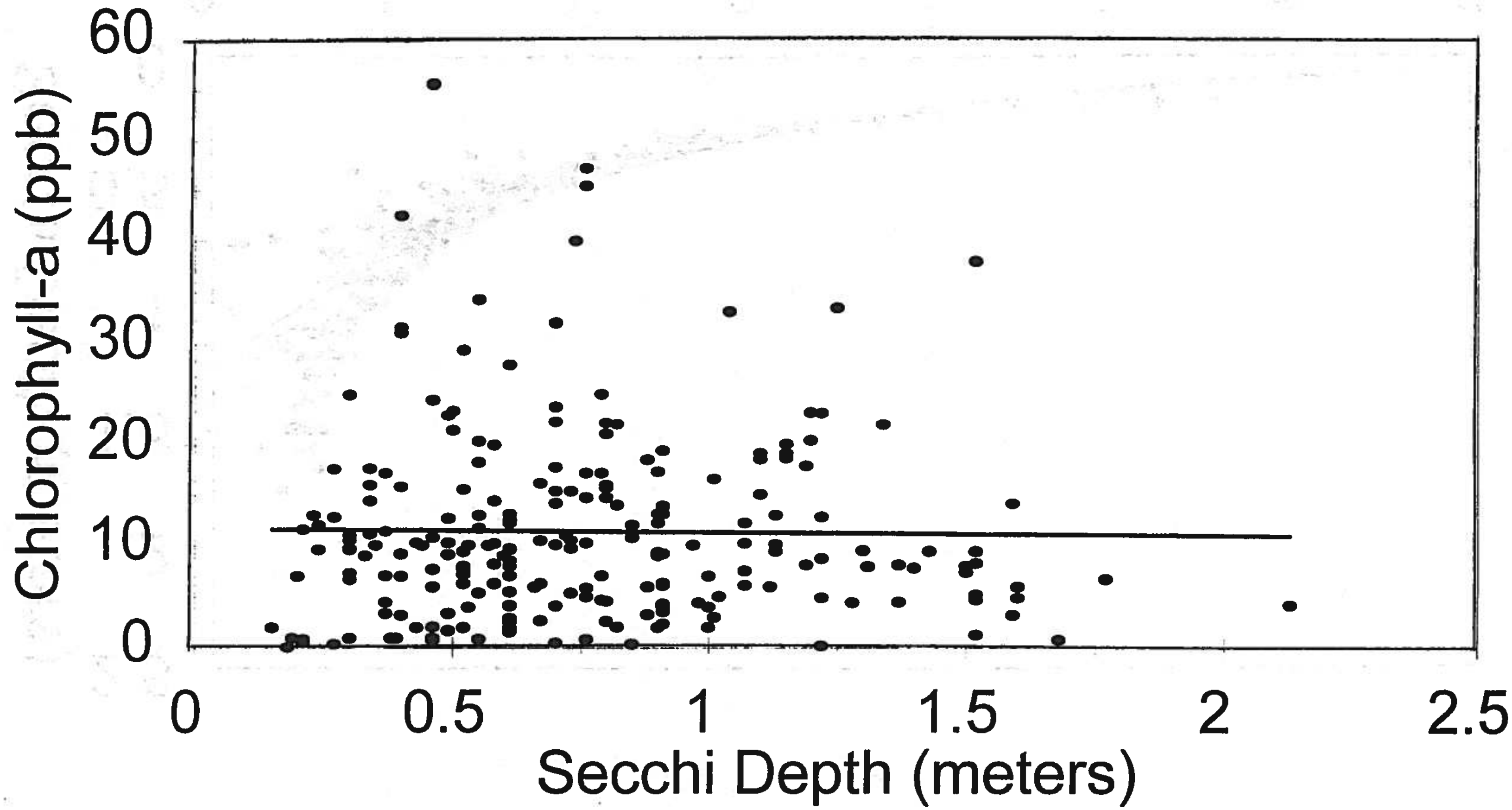
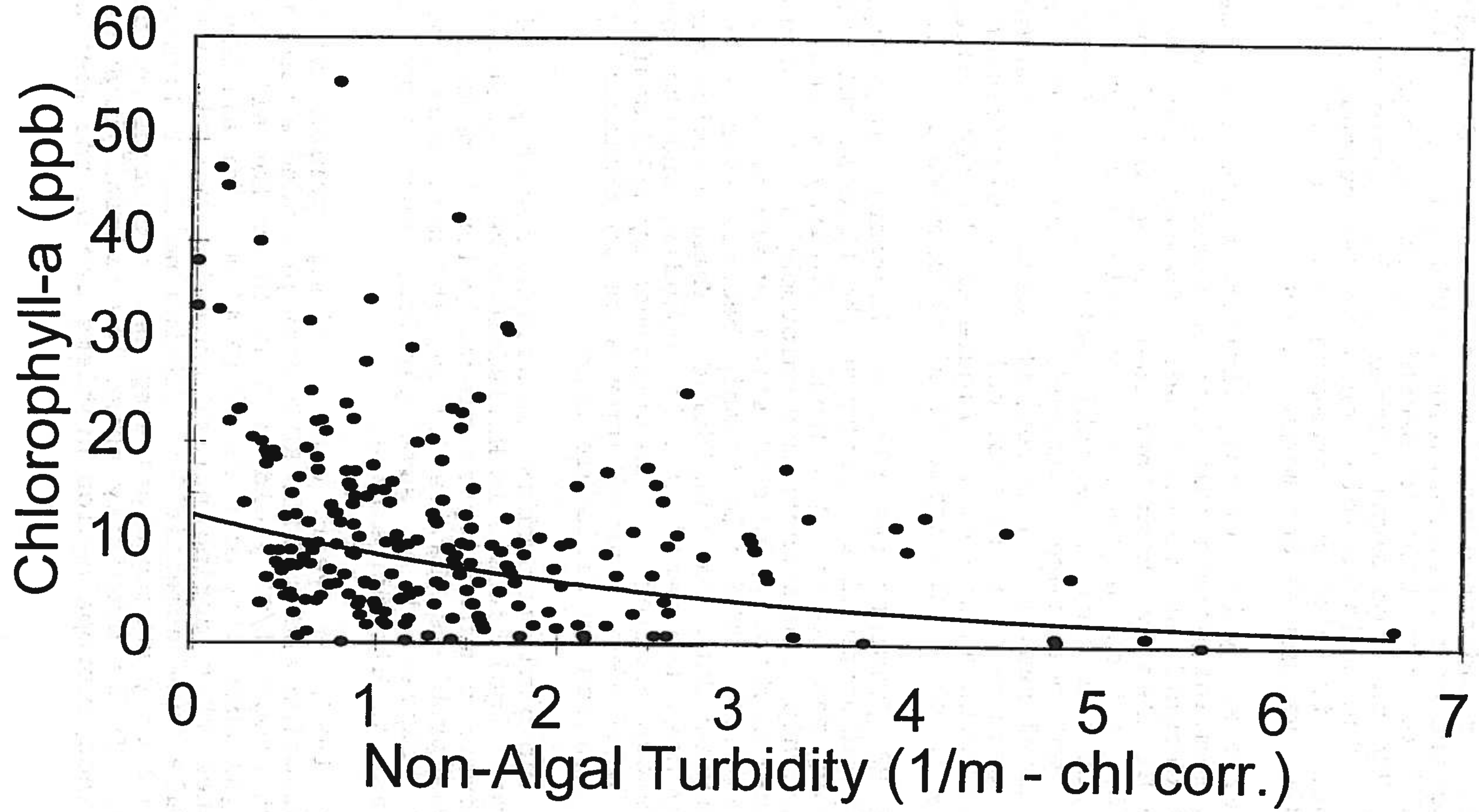


Figure B3. Algal chlorophyll-a versus non-algal (inorganic) turbidity, in Hillsdale Lake, for the period of record (256 data pairs). The best fit line is also indicated.



1983; Walker, 1986). A highly significant relationship ($R^2 = 0.66$, $P<0.001$) is indicated between Secchi depth and non-algal turbidity, upon square root transformation of the latter variable. This means that 66% of variation in Secchi depth readings can be explained solely by the non-algal turbidity (inorganic turbidity) of the water. The relationship tends to be strongest when inorganic turbidity is highest, breaking down at the lower non-algal turbidity values as one might expect.

If water clarity is a primary limiting factor for algal production, then a similar strong relationship should exist when Secchi depth and chlorophyll-a are compared. However, such is not the case. Figure B2 clearly shows that there is no significant relationship between the two. A given chlorophyll-a level is just as likely to occur along a range of Secchi depth values. A number of numeric transformations were examined, to achieve the best possible statistical results. However, the best regression (using a log/log plot) produced a statistically non-significant relationship ($P>0.05$) with an $R^2 = 0.01$. Figure B2 clearly indicates that water clarity is not a predictor of algal biomass in Hillsdale Lake.

Figure B3 presents the plot of inorganic (non-algal) turbidity against chlorophyll-a. Although the highest chlorophyll-a values occur at the lowest non-algal turbidity values, and the best relationship (log transformed chlorophyll-a versus non-transformed non-algal turbidity) is statistically significant ($P<0.001$), the R^2 is only 0.14. The relationship becomes even weaker ($R^2=0.09$) if only summer data are considered. These results confirm what has already been indicated in this Appendix, and what has been stated at numerous meetings and in documents by KDHE staff. Namely, that light is of very limited importance in determining the level of eutrophication in Hillsdale Lake.

Hence, inorganic turbidity can account for only 9% of the variation in summer algal biomass in Hillsdale Lake. Reliance on traditional nephelometric turbidity readings, which have been shown to have numerous problems (Davies-Colley, et. al., 1993), may explain the belief, expressed by some parties, that light limitation is important at Hillsdale Lake.

During 1997, a year with a long period of below normal precipitation and runoff, KDHE data provided a summer time, whole-lake chlorophyll/TP yield of 0.82 (0.49 for all 1997 data) and a non-algal turbidity of 0.31 m^{-1} (0.44 m^{-1} for all 1997 data). This indicates that during normal or below normal rainfall periods, Hillsdale Lake essentially exhibits no light limitation tendency and has a very strong algal response to changes in total phosphorus levels. It is precisely these low rainfall/high water retention times when eutrophication problems are of the most concern.

Lake Protection Under The Revised Loads

The main purpose in determining the phosphorus loads to Hillsdale Lake is so that the "carrying capacity" of the lake can be determined. Carrying capacity, in this case, is the amount of phosphorus per year that will maintain a lake trophic state supportive of all designated uses at the lake. A comparison of the current loads and the loads reflecting this carrying capacity provide a measure of how much load reduction will be needed.

The primary indicator of impaired use is the amount of algal biomass, measured by chlorophyll-a concentration. This measure is used worldwide as an indicator of lake trophic status and as a means of assessing lake use support levels. It has been generally accepted, in both the limnological literature and in surveys compiled by EPA (EPA, 1990), that chlorophyll-a levels above about 10 ppb coincide with the start of algae bloom conditions, visible amounts of phytoplanktonic algae, and the onset of nuisance conditions. Chlorophyll-a mean values of 12 ppb are used as the threshold of transition from "slightly eutrophic" to "fully eutrophic" conditions for Kansas lakes. This 12 ppb value, expressed as a summertime mean, is also used as the mean summer level that begins to impair eutrophication sensitive lake uses, such as recreation and water supply. The Hillsdale Lake Water Quality Project has accepted (as stated during several meetings and in poster displays at meetings) the <12 ppb mean chlorophyll-a goal for Hillsdale Lake.

Given acceptance of this goal for algal biomass, how is it achieved? One cannot place a loading restriction for chlorophyll-a as it is generated in the lake itself. Clearly, the limiting factor controlling lake productivity is the means to control eutrophication. This factor, for the great majority of lake systems, is phosphorus or nitrogen or light availability. Previous arguments have demonstrated that light limitation is slight within Hillsdale Lake and does not control the production of algae except during brief post-storm periods. For the majority of the year, light is plentiful in the mixed layer of Hillsdale Lake.

Walker (1986) provides a metric for determining light availability within the mixed zone of a lake or reservoir. The metric is the depth of the mixed layer (4.76 meters for Hillsdale Lake) times the non-algal turbidity (0.64 m^{-1} for Hillsdale Lake as of 1997), giving a value of 3.05. Walker (1986) states that values below 3 units indicate high light availability while values above 6 units indicate low light availability within the epilimnion. At 3.05, Hillsdale Lake can be said to exhibit relatively high light availability in the epilimnion.

The question of which nutrient is the primary limiting factor is typically determined by nutrient ratios. Total nitrogen-to-total phosphorus ratios less than 7 would suggest nitrogen is the primary limiting nutrient. Ratios greater than 12 would increase the likelihood of phosphorus limitation (Walker, 1986). For Hillsdale Lake the Walker total nutrient ratio ([TN-150 ppb]/TP) over the summer time period-of-record is 17.8, indicating that phosphorus has primary importance. Nutrient ratios outside of the Big Bull Creek Arm are often above 20. Nitrogen may become more important during fall turnover in Hillsdale Lake, based on an examination of seasonal data, but the lake returns to higher nutrient ratios fairly quickly. The conclusion is that phosphorus is the primary limiting factor for eutrophication in Hillsdale Lake.

Therefore, maintaining chlorophyll-a below 12 ppb will require that a threshold value for mean summer total phosphorus not be exceeded. The phosphorus criterion may be determined by calibrating the CNET model with period-of-record lake data, then back calculating what phosphorus level would just meet the 12 ppb criterion. Ninety percent of this phosphorus level (this provides a margin of safety to ensure that mean chlorophyll-a remains below 12 ppb, is consistent with EPA guidance, and is similar to the procedure used by KDHE previously) is used as the final in-lake phosphorus criterion. In the case of Hillsdale Lake, the CNET model indicates that in-lake mean summer phosphorus should be reduced from the current 54.0 ppb concentration to 38.7 ppb. To achieve this level in the lake requires a reduction in the load from the watershed. Table B2 presents the phosphorus load reductions needed to fully support and maintain lake uses into the future.

The load reductions in Table B2 assume that loadings from point and nonpoint sources will be reduced by the same percentage, and that atmospheric sources are beyond our ability to reduce. Percentage reductions are very similar to those originally calculated in 1994. The absolute mass reductions originally proposed by KDHE are also very similar to the available load reduction amounts in Table B2. In essence, to achieve in-lake water quality goals, available phosphorus loads must be reduced by at least 43% or 7,790 kg/yr. Total phosphorus loads must also be reduced by at least 44%, 28,343 kg/yr. These load reductions are based on yearly mean values. This means that while different reductions could, and would, be achieved on a given year (due to variability in climate and hydrology), over the long-term the goal is 28,343 kg/yr, with at least 7,790 kg/yr being reductions in available phosphorus forms. The difference, 20,553 kg/yr, could be aimed at either soil erosion control (attached phosphorus) or additional reductions in more soluble forms.

The reductions in point sources reflect, generally, reductions in available phosphorus. These can be consistently achieved, year-to-year, by using tertiary removal technologies or by routing discharge out of the watershed. The reductions in nonpoint sources are another matter. Year-to-year reductions will vary to a great degree because of variations in yearly rainfall, runoff, land use management, and variability in hydroperiodicity. The measure of success, in terms of nonpoint source load reductions, would not be based on a given year, but on compliance over many years with the average annual reduction value. Nonpoint compliance would be based on the use of a mixture of best management practices for crop production, feedlot manure containment, urban runoff treatment, pasture management, etc. While many of the practices would be structural for cropland and feedlots, many others would be non-structural. These non-structural best management practices would revolve around fertilizer reduction plans for agricultural and urban areas, septic system maintenance (for failing systems or systems near the lake or inflows), and pasture management.

Table B2. Carrying capacity phosphorus loads for Hillsdale Lake including load reductions from current levels.

Parameter	Carrying Capacity Load		Reduction From Current Load		
Phosphorus Loading					
Total P-Load					
Atmospheric	853	kg/yr	0	kg/yr	0%
Point Sources	2,819	kg/yr	2,231	kg/yr	44%
Nonpoint Sources	33,003	kg/yr	26,112	kg/yr	44%
Total	36,675	kg/yr	28,343	kg/yr	44%
Available P-Load					
Atmospheric	426	kg/yr	0	kg/yr	0%
Point Sources	2,255	kg/yr	1,785	kg/yr	44%
Nonpoint Sources	7,591	kg/yr	6,005	kg/yr	44%
Total	10,273	kg/yr	7,790	kg/yr	43%

Parameter		Units	
Summer Water Quality (Whole-Lake, Under Reduced Loads)			
			Relative Improvement
Mean In-Lake TP	38.7	ug/L	28%
Mean Chlorophyll-a	11.0	ug/L	21%
Mean Secchi Depth	1.07	meters	8%
Nuisance Algae Frequency	33.6	% of summer	45%

The gain from such load reductions would be worth the effort in terms of maintaining a high quality lake for the use of the public. Benefits would include reduced costs for future water supply, increased recreational revenues, longer use-life for the lake (reduced sediment accretion), and improved fisheries and wildlife habitat. Frequency of nuisance algal conditions would be reduced by about half during the summer. Gains would also accrue to landowners in the watershed, in terms of maintaining soil productivity through fertilizer management without current soil losses. Direct economic gains from water quality protection at Hillsdale Lake could be immense. Many recent studies indicate that water quality related recreational benefits (not considering water supply benefits), for larger lakes, may be in the range of tens-of-millions of dollars per year for local economies (A.L. Burruss Institute, 1997; Boyle, et. al., 1997).

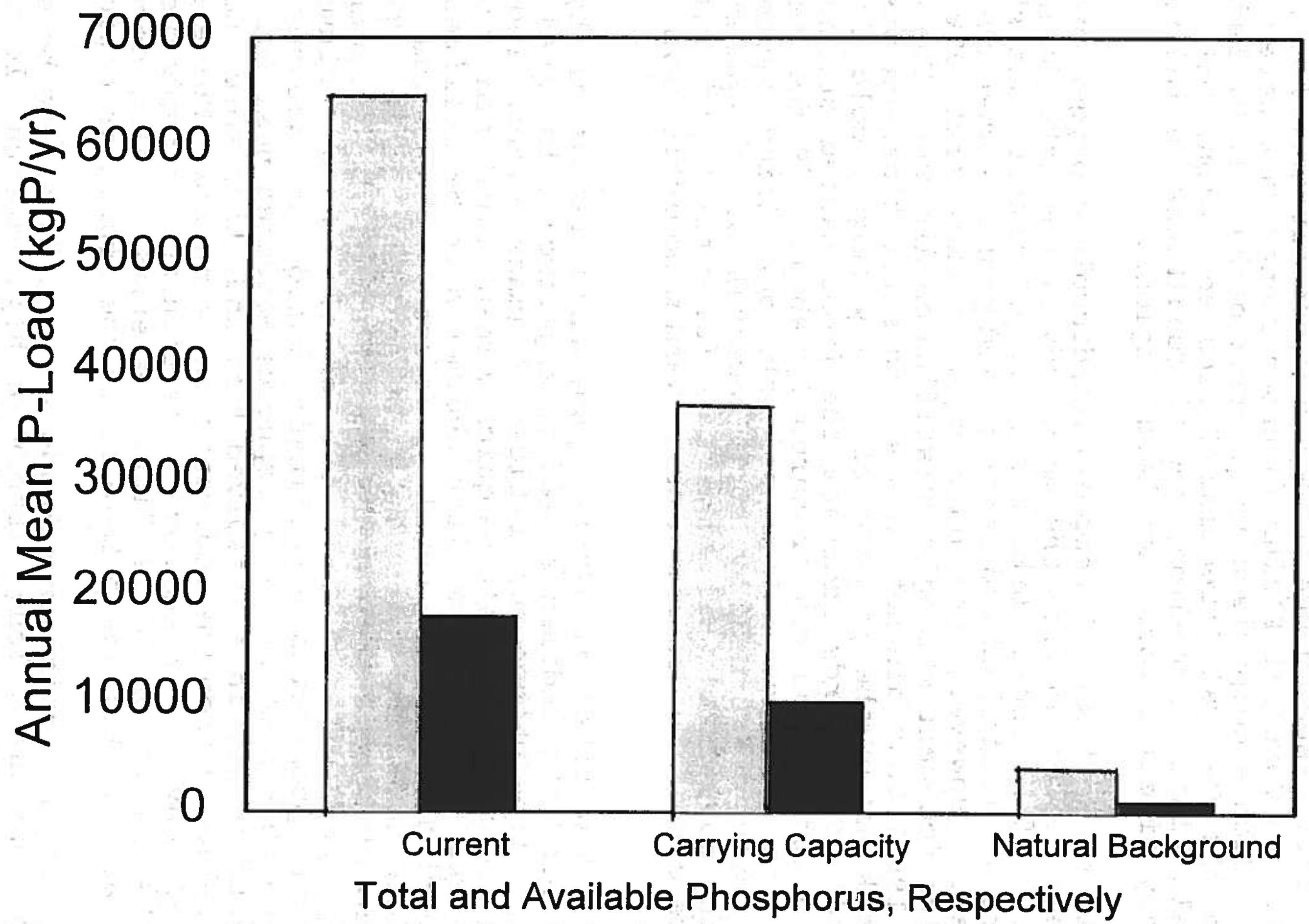
Figure B4 illustrates the current load and proposed load reductions in a visual fashion. While a 44%, 28,343 kg/yr, phosphorus reduction may seem large, it is far from what might be termed a return to "background" levels under pre-settlement watershed conditions. Model simulations of Hillsdale Lake water quality under pre-settlement land use conditions suggest that current loads are about 1,677% of natural background. Current in-lake total phosphorus levels, chlorophyll-a levels, and water clarity are 621%, 636%, and 71% of background levels, respectively. The proposed carrying capacity goals represent a reduction of only 0.33 kgP/watershed acre/yr, which includes both point and nonpoint sources.

Past discussions have implied that there is some interchange of phosphorus between sediment and water column in Hillsdale Lake. While there certainly must be some level of exchange, the magnitude of water-to-sediment transfer is believed much greater than sediment-to-water transfer. Walker (1986) discusses five characteristics of lakes and reservoirs that promote the existence of a significant "internal load" of phosphorus from lake sediments.

First, lakes with significant internal phosphorus loading will have high ortho/total phosphorus ratios in inflow streams dominated by nonpoint sources of pollution. High ratios imply a large input of directly available nutrient material. The largest nonpoint source stream in the Hillsdale Lake watershed, Rock Creek, has baseflow maximum ratios of about 25%. Most observations fall in the range of 11%, or less. Hillsdale Lake fails the first criterion.

Second, lakes with low hydrologic overflow rates are more susceptible to having significant internal phosphorus loads. Lakes with lower overflow rates may not be able to flush released sediment phosphorus out of the lake, allowing it to be utilized by algae. The overflow rate for Hillsdale Lake is calculated at 4.9 m/yr, as of 1997. The second criterion is met (CNET documentation indicates values <5.1 m/yr are considered low), providing a vehicle for internal loads to cause eutrophication if such internal loads occur.

Figure B4. Visual presentation of current, carrying capacity, and "natural background" mean phosphorus loads to Hillsdale Lake.



Third, lakes that are polymictic (stratify and destratify during the summer many times) tend to have greater impacts due to internal phosphorus loads. Such a condition allows released phosphorus to interact with surface waters all through the summer, instead of just during fall turnover. Hillsdale Lake has been promoted as polymictic, based on EPA ecoregional descriptions for lakes within the Western Cornbelt Plains (Johnson County Wastewater comments to KDHE). Such a comparison is in error because 1) Hillsdale Lake is within the Central Irregular Plains ecoregion, not the Western Cornbelt Plains ecoregion, and 2) conditions in individual lakes may vary widely across such large regions.

For Hillsdale Lake, 35 temperature/dissolved oxygen profiles have now been collected from the main body of the lake during July and August. If Hillsdale Lake was truly polymictic, one should see a mixture of stratified and unstratified profiles when these data are plotted. However, the data clearly show that 97% of summer profiles document strongly stratified conditions. The one profile (July 1987) that did not show strong stratification was collected one week after the passage of a very strong cold front. NOAA climatologic records indicate the front caused strong winds and dropped daily high temperatures by about 10°F for several days after its passage. Even strongly stratified systems can be temporarily disturbed by such powerful storm systems, without implying polymixis. Hillsdale Lake fails the third criterion, and is more correctly described as a "warm monomictic" system (Wetzel, 1983).

Fourth, low total iron/total phosphorus ratios in hypolimnetic waters near the sediments lead to significant internal phosphorus loads. Iron/phosphorus ratios <3 (mass ratio) indicate that released phosphorus can't be quickly re-precipitated, thus allowing phosphorus released from lake sediments to be utilized by algae. The period-of-record total iron/total phosphorus ratio for Hillsdale Lake, for waters near the sediment, is 18. This implies that any phosphorus released from Hillsdale Lake sediments will be quickly precipitated back out of the water column. Total iron/ortho-phosphorus hypolimnetic ratios are greater than 205, implying that most of the phosphorus measured near Hillsdale Lake sediments is not in a dissolved form and, therefore, not material being released from the sediments due to anoxia. While some of the material may be resuspended particulate phosphorus (due to currents), most of it is likely material raining down from the upper waters. Hillsdale Lake fails the fourth criterion.

Fifth, internal phosphorus loads are more likely to be significant if the lake has a long history of high external loads and high material retention. Such conditions create a reservoir of nutrients that might later become the source for internal loadings. Hillsdale Lake likely does have a high material retention, as do most larger lakes, but the lake has not been accreting materials for more than 15 years. Hillsdale Lake has not had time to accumulate a large reservoir of phosphorus in sediments, although inaction in the present may create such a problem for the future. Hillsdale Lake fails the fifth criterion, at least for now.

Based on the discussion of these five criteria, one must conclude that Hillsdale Lake is unlikely to have a significant internal load of phosphorus at present. Thus, this component is left out of nutrient load calculations. In fact, new lakes typically spend the first few years after impoundment releasing soil phosphorus to the overlying waters until they reach equilibrium. This often provides a productivity "spike" for new lakes, during the first few years, that provides better than expected fishing during the first decade. After equilibrium is reached, fishing productivity tends to decline back towards normal levels causing fishermen to claim that problems are developing with the fishery. In actuality, the "boom" during the first few years of a new lake cannot realistically be maintained. Current claims that the fishery of Hillsdale Lake is declining may simply be the return to long-term condition that would be expected. Concurrently, net accretion of sediment phosphorus may only have a history of about 5-to-10 years in Hillsdale Lake.

Yet another possible explanation of the perceived changes in fishing quality at Hillsdale Lake was expressed to KDHE staff at a recent boating safety workshop. The person who provided their opinion is a professional bass fisherman who has spent significant amounts of time fishing Hillsdale Lake. This citizen's conclusion was that turbidity is not affecting the fishery (although he felt sedimentation in the uppermost reaches of the lake to be significant), but that fishing quality has declined due to extreme fishing pressure. Apparently Hillsdale Lake is a tremendous recreational resource for the area, making pollution prevention a true investment for the future and the local economy.

<u>1997 Water Quality Data, Comparison To 1993-1996 Data</u>

As has been previously stated, an intensive program of water quality data collection began during the flood year of 1993 at Hillsdale Lake. The four years of 1993-to-1996 were either above normal in terms of rainfall, or above normal in terms of inflow and outflow (shorter than normal hydrologic retention times). The year of 1997, at least on an annual time-scale, was also slightly above normal. However, rainfall and runoff during the final portion of the year, including all of summer, was far below normal. This provided an opportunity to compare a block of data collected from above normal hydrologic conditions to a time period with very dry conditions. Planning for eutrophication management is very dependant on these "dry" periods. The impacts of excessive nutrient loads will be most observable during times of longer hydrologic retention, without the disruptive influence of runoff "overflows," as was discussed previously.

Annual rainfall during 1997 was slightly above normal (112% of long-term mean) at Hillsdale Lake, primarily due to large rainfall amounts during a period in May. However, summer rainfall was only about 75% of what would be considered normal for the June-to-September time period. Runoff, as estimated by lake outflow records, indicates an even more pronounced difference over the year. The January-to-June period of 1997 saw lake discharge at about 170% of what would be considered normal for the first half of the year, based on annual average conditions. Conversely, the July-to-December period had only 55% of what might be considered normal for the year. The July-to-October discharge period (believed comparable to the June-to-September rainfall period) accounted for only 16% of the year's discharge, or 25% of what might be considered normal for the yearly average.

Hydrologic retention times in Hillsdale Lake were calculated based on conditions at different times during 1997, extrapolated to the entire year, as a means of comparing the different time periods. The entire year of 1997 had a hydrologic retention time of 0.86 years (long-term mean value is 1.1 years). If conditions during the first half of 1997 were descriptive of the entire year, hydrologic retention time would have been 0.26 years. If conditions during the last half of the year were descriptive of the entire year, hydrologic retention time would jump to 1.27 years. Finally, if July-to-October conditions had been descriptive of the entire year, hydrologic retention time would have been 1.85 years. This clearly shows that while 1997 was slightly above normal hydrologically, the year contained a prolonged period of dry, below normal, hydrologic conditions for comparison. Given that many communities in northeast Kansas were several inches below normal for their yearly precipitation, the "normal" annual condition at Hillsdale Lake might be considered a regional anomaly.

Table B3 presents data from both the 1993-to-1996 time period and from 1997. The 1997 KDHE data were collected from a period where there had been no significant rain and runoff for at least three weeks. Indeed, the only significant inflow for either of the main tributaries would have been the "trickle" of point source discharges during this period. This was typical of late 1997 conditions as well as typical for other below normal precipitation years. As can be seen, conditions do vary between time periods, both for the whole lake as well as for individual stations. The largest differences in lake trophic state condition occur in the main body of the Big Bull Creek Arm of Hillsdale Lake, where point and nonpoint source contributions of phosphorus are greatest.

Table B3. Comparison of Hillsdale Lake chemical and biological water quality for the period 1993-to-1996 versus 1997. TP = total phosphorus, TN = total nitrogen, SD = Secchi depth, Chl = chlorophyll-a, NAT = non-algal turbidity, TN/TP = Walker nitrogen/phosphorus ratio, COD = chemical oxygen demand, BOD = five day biochemical oxygen demand, ppb = ug/L, and ppm = mg/L.

Station/Time Period	Parameter/Units							
	TP ppb	TN ppb	SD cm	Chl ppb	NAT 1/m	TN/TP -	COD ppm	BOD* ppm
Station 1 (Main Lake)								
1993-to-1996	43.5	993	115	11.9	0.57	19.8	-	2.4
1997	23.4	921	123	11.3	0.53	33.2	5.1	2.4
Station 2 (Big Bull Arm)								
1993-to-1996	69.2	983	62	13.8	1.26	13.0	-	2.1
1997	77.5	1182	57	48.3	0.55	13.3	23.2	6.3
Station 3 (Little Bull Arm)								
1993-to-1996	55.7	883	83	15.7	0.82	14.8	-	2.1
1997	39.3	914	100	8.8	0.78	23.6	3.4	2.4
Whole-Lake Mean								
1993-to-1996	56.2	953	87	13.8	0.81	15.8	-	2.2
1997	46.7	1005	93	22.8	0.50	23.4	15.9	3.7

* = Pre-1997 BOD data collected from 1993 and 1995 only.

Table B3 continued.

Station/Time Period	Parameter/Units Cell Count #/mL*	Blue-greens Percent	Biovolume ppm*	Blue-greens Percent
Station 1 (Main Lake)				
1993-to-1996	3465	25%	4.39	13%
1997	3717	40%	3.56	8%
Station 2 (Big Bull Arm)				
1993-to-1996	2615	0%	3.68	0%
1997	8379	37%	29.53	4%
Station 3 (Little Bull Arm)				
1993-to-1996	4158	33%	2.77	40%
1997	2709	34%	3.73	5%
Whole-Lake Mean				
1993-to-1996	3413	19%	3.61	18%
1997	4935	37%	12.27	6%

* Pre 1997 cell count data collected from 1993 and 1996 only; biovolume data collected from 1996 only.

Average phosphorus concentrations were lower for most of Hillsdale Lake during 1997, than for the previous years, with the exception of the Big Bull Creek Arm. Total phosphorus levels were higher on average for this arm of the lake than they were during higher rainfall periods. Even during 1993-to-1996, the Big Bull Creek Arm has shown consistently higher levels of phosphorus than other locations in the lake due to unabated inputs from point sources during low flow and elevated inputs from nonpoint sources during high flow. This condition is typical of what is generally observed for nonpoint and point source impacted waterbodies. Nonpoint source impacted waterbodies tend to be "cleaner" during baseflow periods and "dirtier" during runoff. Point source impacted waterbodies often show the reverse because dilution with runoff can reduce the overall pollutant (e.g., phosphorus) concentration.

Average total nitrogen concentrations in Hillsdale Lake did not appear to vary as much, yet followed a pattern similar to that for phosphorus. Levels of total nitrogen in 1997 were elevated in the arms of the lake but lower than usual for the lake as a whole. This is likely attributable to point source discharges occurring without dilution from runoff events, as mentioned before.

Water clarity, as measured by Secchi disk depth, increased along with drier conditions, except in the Big Bull Creek Arm. While the clarity of the main lake and the Little Bull Creek Arm remained fairly similar, the Big Bull Creek Arm tended to be considerably less clear regardless of time period.

Algal biomass, as measured by chlorophyll-a, was fairly similar across the lake during 1993-to-1996. While Stations 1 and 3 maintained a general similarity in 1997, the Big Bull Creek Arm did not. Chlorophyll-a readings from this station (KDHE data) set new records for the lake during 1997 (75-to-95 ppb). This was believed due to higher retention time, in both the arm and whole lake, and higher levels of immediately available phosphorus from point sources entering Big Bull Creek. The percent of summer that would see chlorophyll-a levels greater then 12 ppb is about 61% for long-term condition. For 1997, the percent of summer with nuisance algae conditions rose to >95%, clearly indicating the impact of dryer conditions.

Non-algal turbidity was less in the main body of Hillsdale Lake than in the arms of the lake. For the main body and the Little Bull Creek Arm, values do not differ significantly between time periods. However, conditions in the Big Bull Creek Arm differed greatly between time periods. During 1993-to-1996, the Big Bull Creek Arm appeared to experience some degree of light limitation following runoff events. During 1997, the lake received little runoff and was characterized by higher algal biomass. During high precipitation periods, therefore, light limitation appears to exert a slight influence in the upstream reaches of the lake, while in low precipitation periods the lake does not experience light limitation to any significant degree.

Nutrient ratios differed significantly between the Big Bull Creek Arm and the rest of Hillsdale Lake. During wet years, the main body remains phosphorus limited while upstream areas of the lake show a lower indication of phosphorus limitation. During dry years, even the upper reaches were probably phosphorus limited, except for the Big Bull Creek Arm. In this arm of Hillsdale Lake, the consistent discharge from point sources maintained an abundance of phosphorus in the water column.

Data for chemical (COD) and biochemical (BOD) oxygen demand were not collected consistently as part of the Hillsdale Lake Water Quality Project. Most pre-1997 BOD data came from 1993, with a couple of samples from 1995. To date, COD data has not been collected by the Hillsdale Lake Water Quality Project. KDHE staff collected BOD and COD samples in 1997 to establish baseline data for these two parameters.

Concentrations of BOD and COD in Big Bull Creek were again different from those in the remainder of the lake. Specifically, COD was 4-to-7 times higher and BOD was almost three times higher in the Big Bull Creek Arm than elsewhere in the lake. These two parameters further demonstrate the important role of point sources in terms of lake eutrophication and organic enrichment. While BOD concentrations in the main body and Little Bull Creek Arm were similar during the two time periods, concentrations in the Big Bull Creek Arm were three times greater during the dry time period.

Variations in the density and structure of the phytoplankton community reinforced the trends observed in Hillsdale Lake chemical data. Both whole-lake mean cell count and algal biovolume were higher during 1997 than during 1993-1996. Nuisance blue-green algae also achieved their highest levels during 1997, although the dominance of the Big Bull Creek Arm community by euglenoid algae (large individual cells) had an impact on the biovolume data. A qualitative examination of the zooplankton community during 1997 indicated that the Big Bull Creek Arm had a higher total count and a higher total number of cladocerans than did the other stations. However, it had similar numbers of copepods, rotifers, and large filter feeding forms.

Conclusions

There are several conclusions that can be drawn from the available data for Hillsdale Lake.

1. Phosphorus loads are likely greater than suggested by previous studies. However, the majority of this phosphorus appears to be highly refractory, settles out fairly quickly, and does not really contribute to lake eutrophication. The "available" or "effective" phosphorus load appears very similar to the

estimates for total phosphorus derived from previous KDHE studies.

2. Nonpoint sources account for a majority of the total phosphorus load to Hillsdale Lake (about 91% maximum) while point sources account for about 8% (minimum). However, in terms of available phosphorus, point sources account for <u>at least</u> 22% of the total (perhaps as high as 30%). Both point and nonpoint sources must better control phosphorus loading in order to achieve the targeted lake condition.

3. Sediment accretion rates of less than 1 cm/yr appear applicable to the lake as a whole (USGS, 1997). It is likely that recent claims of a degrading fishery are not related to excessive siltation and turbidity. Rather, declines in fishery represent a return to normal productivity levels, down from the post-impoundment productivity "spike" described in the literature for new impoundments, or are due to over-fishing, or both.

4. Light availability does not play a significant role in limiting phytoplankton in Hillsdale Lake, except during temporary time periods such as spring runoff and post-storm events. During these temporary periods, the effects tend to be more pronounced in the upstream reaches of the lake, rather than in the main body.

5. Hillsdale Lake is not believed to experience significant "internal" loading of phosphorus. However, this may change if the lake is allowed to accumulate high levels of phosphorus for many years.

6. Protecting the lake during low precipitation years, when the effects of excessive nutrients and eutrophication would tend to be most evident, should be a priority in pollution reduction plans. The 1997 data demonstrate that drier years have greater observable impacts. These data also indicate that the point and nonpoint sources of phosphorus in the Big Bull Creek sub-watershed offer the best opportunity for phosphorus reductions and water quality improvements.

7. Despite recent revisions to the initial phosphorus loading estimates, the percentage reductions needed to achieve the targeted water quality conditions have remained relatively consistent over the past few years (KDHE, 1994). The areal phosphorus load reduction, necessary to maintain less than 12 ppb chlorophyll-a in Hillsdale Lake, is only 0.33 kgP/acre/year (reduction in available forms = 0.09 kgP/acre/year). The current phosphorus load is 15-to-20 times greater than loads associated with "natural background." Current mean total phosphorus and chlorophyll-a are between 5-to-7 times greater than would be expected under pre-settlement

watershed conditions.

8. Although the observed chlorophyll/phosphorus yield ratio suggests that Hillsdale Lake is moderately responsive to changes in phosphorus concentration, this nutrient is still the primary limiting factor controlling eutrophication in the water column. In terms of lake management, the initial phosphorus load reductions will promote greater phosphorus limitation due to declining supplies of the nutrient. This, in turn, will increase the relative impact of additional year-to-year phosphorus reductions. Water quality improvements may be slower to occur in the first years of pollutant reduction, but will likely gain momentum as time and pollutant reductions continue.

9. Although the water quality of Hillsdale Lake is still reasonably good, it is unwise to assume that conditions will not worsen with time. Lakes, by their very nature, accumulate materials and pollutants and experience declining water quality over time if not carefully protected and managed. In order to maximize the useful lifetime of this lake, pollution prevention and active lake management must be practiced. Phosphorus load reductions for Hillsdale Lake represent a proactive (and therefore more economically efficient) approach to improving and maintaining water quality. Allowing the lake to degrade to the point of use impairment, and then attempting to restore it, will prove extremely expensive and have a much lower likelihood of success. Allowing the lake to degrade will have significant negative impacts on the area economy and water supply in the future.

10. Recent discussions have led some parties to believe that phosphorus load reductions are being proposed for Hillsdale Lake in order to improve average water clarity for the benefit of recreation. This view is incorrect. While water clarity would likely improve slightly, owing to phosphorus/sediment load reductions, the overall improvement would not likely be great (see Table B2). The primary management focus for the protection of water quality in Hillsdale Lake is, and has always been, towards maintaining a chlorophyll-a concentration of less than 12 ppb on average (i.e., maintaining the lake at the low end of the eutrophic classification, or lower). This goal <u>can</u> be achieved through phosphorus load reductions, and will result in water quality benefits for both recreation and water supply, which will ultimately benefit the local economy.